Physics of the ether

S. Tolver Preston

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PHYSICS

OF THE

ETHER.

BY

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LONDON:
E. & F. N. SPON, 48, CHARING CROSS.
NEW YORK:
446, BROOME STREET.
1875.

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PREFACE.

THE present work, the result of much thought and careful study, is intended to afford an explanation or insight into the mode of working of an important series of physical phenomena at present referred to the theories of "*action at a distance*" and "*potential energy.*" The subject dealt with includes the general phenomena of the aggregation of molecules, at present referred to "*cohesion,*" &c.; and the mutual—strikingly diversified—actions of dissimilar molecules, at present referred to "*chemical affinity,*" including the remarkable development of molecular motion taking place in the phenomena of combustion and in the case of explosives, referred to "*potential energy;*" comprising also the movements of approach and recession of bodies in the "electric" condition (or when "statically charged") and the general effects comprised under the phenomena of "*attraction* and *repulsion.*"

The first part of the work contains an argument designed to prove that the allied theories of "*action at a distance*" and "*potential energy*" (i.e. the existence of *two* forms of energy, or an energy *without motion*) are inadmissible. The second part, or greater bulk of the work, is devoted to a consideration of the mode in which the above-named series of physical phenomena are brought about, or the regulating physical processes therein concerned. It is hoped that the arguments in the first part of the work will be received in the spirit in which they are written, i.e. not in a captious spirit, but keeping in view the attainment of truth as the ultimate object.

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PART I.

1. The influence of the theory of "action at a distance" in physical science is well known, and need not be commented on. We shall proceed to examine this theory briefly. If our manner of dealing with the subject be somewhat broad or plain-spoken, this is with the view to clearness, our aim being simply to arrive at truth.

Firstly, this theory assumes that one mass of matter can move or act upon a second mass of matter, placed at a distance, without the intervention of material or physical agency; or the theory assumes that a mass of matter might be surrounded to a considerable distance by absolutely empty space, and yet that the mass might be put in motion without the penetration of matter in any form into this empty space surrounding the mass.

We will take the case termed "gravity." Here it is assumed that a mass of matter can be accelerated or put in motion at different rates by a simple change in its position in empty space, by which its distance from a second mass is varied, without the necessity for the presence of a medium or anything whose physical condition might be affected by the variation of distance between the masses, i. e. without the necessity for the presence of matter or any material means to produce and regulate the different degrees of energy with which the mass is acted upon in different positions; or it is assumed that the mass can be acted upon or moved with different degrees of energy (found to have a somewhat complicated relation to the relative distance of the masses), without the presence of any material means to regulate the varying energy with which the mass is acted upon in the different position: in short, a mass of matter may be wandering about in space some thousands of miles away from anything to control its motions, and yet it is assumed that the mass, by simply passing from one point of empty space to another, can have its velocity adjusted in proportion to the square of its distance from another mass. We can imagine nothing more opposed to reason than this, if the question be fairly looked at.

It is important to distinguish between the fact of this exact adjustment taking place, and the cause, for no one doubts the fact; but the theory would assume that there are no varying

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physical conditions about the mass required to produce the varying effects; or, in other words, that by a mere change of distance the physical effects can vary, without the physical conditions about the mass having undergone any change. Surely the only conceivable way in which the mass could be differently affected at different distances, would be by the presence of something about the mass, whose physical condition might be affected by the distance, for the mass itself cannot possibly be physically affected by the distance.

2. It is sometimes said that this is a "property" of matter or a "law," as if to imply that this in itself constituted a reasonable basis for the assumption or theory, but it is clear that this is merely to assume that it is a fact; for of course a mass of matter may be readily assumed to have the property of doing anything, however incredible; but this would be only assuming the thing to be a fact without a reasonable ground to support the assumption.

Surely, if a thing be stated to be practicable, the least to be required is that some idea should be formed of the means by which the result or mechanical end is to be attained, and this perception of the means constitutes the sole ground to support the assumption as to practicability. If, on the other hand, a thing be assumed to be practicable without any perception of the means, then the assumption falls away of itself from want of ground to support it.

It may be said to be a *law* or *property* of light to vary as the *square of the distance*, but this does not render less essential the existence of regulating physical conditions to produce this special mechanical effect.

Again, in the case of the movement of approach of two masses towards each other, it is sometimes said that the one mass "attracts" the other, or that it is *due to* "attraction," as if to imply that this constituted in some way an explanation of the effect. To constitute an "explanation," however, something at least must be added to our present knowledge. Before this phrase "attraction" was applied, the remarkable effect was observed that two masses of matter exhibited a tendency to move towards each other, and when free to move, moved towards each other, without anything being known as to the cause of this effect: after the application of this phrase "attraction" the same effect was observed with no further addition to knowledge, so that the application of the mere phrase evidently can teach nothing. It is of course necessary to have some phrase as a convenient means of reference to the case, and the term "attraction" may serve as well as any other; just as the term "repulsion" serves to refer to the opposite movement; as, for example, the repulsion of a pith ball by an electrified body; but to assume that this term gave any insight into the cause of the movement would be very like assuming that the *repulsion* of the ball was due to *repulsion*.

A vibrating tuning-fork is known to attract a piece of card, or to

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cause a piece of card to exhibit a tendency to move towards it; but the term "attract" can evidently give no insight into the physical cause. The same considerations apply as regards the remarkable tendency exhibited by a piece of iron to move towards another piece when in that special physical state termed the magnetic state. The phrase may be varied at will, and can avail nothing, so long as no clear idea is formed of the means by which the mechanical end is attained. Before the atmospheric pressure was recognized, a pump was considered to have some mysterious power of drawing fluids, and the effect was sometimes said to be *due to* "suction." It is an observed fact that the molecules of a solid hold together in a state of cohesion; or, although these molecules are wholly unconnected and a certain distance apart, they are nevertheless maintained in positions of stable equilibrium, so that a certain resistance is encountered when the attempt is made to move them to a greater distance apart. This resistance of the molecules to separation is sometimes said to be *due to* "cohesion," which certainly would have the appearance of implying that the *cohesion* of the molecules was due to *cohesion*. It is unquestionable that a certain abuse of terms or phrases exists, which appear in some cases to take the place of physical causes. The term "chemical affinity" affords another example, of which others might be given.

3. There is another point in connection with the theory of "action at a distance." It is assumed that time is not required for the effect at a distance to be produced. Thus, if we take the case of an electromagnet and a piece of iron at a distance: then when the electromagnet is suddenly put in the "magnetic" condition by the electric current, it is assumed, in accordance with this theory, that the agency by which the distant piece of iron is put in motion requires no time to pass from the magnet to the iron. Now surely for the piece of iron to be affected, the agency, whatever it be, producing the effect, must cross the intervening interval to get at the iron; and how can it be assumed that no time is required for the transit? It is difficult to see how this would avoid the absurd postulate of an infinite velocity, the speciality of which would be that that which passes would require to have the peculiar property of occupying the beginning, the end, and every intermediate point of its path at the same instant. What is it that the theory really means to put forward? Is it an admission of spiritualism? If it be assumed that intervening matter is here not concerned in producing the movement of the piece of iron, then how is the implied inference as to the intervention of spiritualistic agency to be avoided? There can be no question that this theory is distinguished for a remarkable vagueness, and a complete absence of demand for the exercise of the intellectual powers. Can it be said, and if so in what respect, a clearer idea admits of being formed of the means by which motion is produced, when it is referred to "action at a distance," and when it is referred

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to "psychic force." One noteworthy point in connection with theories of a vague nature is, that their very vagueness, in which their real weakness consists, is employed as a defence against argument: hence the long life of such theories.

4. Another important consideration in connection with the theory of "action at a distance," is the practically unlimited application of which such a principle admits. It is a point very generally recognized that all physical phenomena or effects are effects of motion, or that physical phenomena, whatever their diversity, are all correlated in this fundamental respect. If, therefore, the principle be once conceded that motion can take place without physical agency, or that the mere presence of a mass of matter suffices to produce motion, then how is it possible to know what might not occur, since all physical effects are effects of motion, or how could there be a rational guide or regulating principle to physical causation left?

In fact, the very movements to which this theory of "action at a distance" is chiefly applied, viz. the movements of approach and recession of masses and molecules of matter, constitute the fundamental and most important movements concerned in the working of physical phenomena. If, moreover, these movements may vary in energy at different points of space, or at different distances, without regulating physical conditions, as this theory supposes, then what result might not be attained by the free application of this theory, which from its very nature may be made to include all physical phenomena?

One of the most palpable facts to any impartial observer will be the extraordinary number of hypotheses that do exist regarding the working of physical phenomena, all built upon this principle or theory; in fact, the principle from its very nature admits of an endless variety of applications, and from the vast number of hypotheses which present themselves by a recognition of this theory, a certain and final solution to a physical problem is rendered impossible. In fact, the very fertility of resource given the fancy by this principle renders the problem insoluble. In short, it must be plain that a principle which would put physical causation under the control of phantom agencies, and which allows physical effects to be brought about much according to the fancy, itself completely precludes the possibility of determining what the facts are.

5. There is another point in connection with this theory. If all physical phenomena or effects be effects of motion, and if, in any case when motion is observed to take place, a rational cause or process capable of being appreciated by the mind is required; then, as a point of principle, why should not such a cause be required in all cases, since all cases are fundamentally of the same kind; or how can it be logically consistent to draw distinctions when the principle involved is the same?

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Thus, if it be considered as a point of principle inconsistent or even absurd to assume that the heat (motion) produced in a focus of invisible heat rays has been developed without material or physical agency; then as a point of principle must it not be equally absurd to assume that the motion produced in a distant pith ball by an electrified body has been developed without physical agency?

6. Again, if all physical effects be effects of motion, then, in principle, the one fundamental cause for investigation must be the cause of motion, or the cause determining the vast variety of motions constituting physical phenomena. To admit, therefore, a theory which would do away with the necessity for investigating the cause of motion, would be to admit a principle which, if carried out universally, would close the field for physical research altogether, or which would assume that physical effects were inexplicable; for if every motion were referred to this theory of "action at a distance," there would be no realizable physical cause left to investigate; and the course taken would be simply to observe physical effects, and to apply this theory, without making thereby one practical addition to knowledge as regards physical causation. We merely put forward that this would be only carrying out in its entirety a principle which has already been carried out to a very great extent.

Thus, for example, all the varied and remarkable effects of chemical action, or those remarkably diverse movements of molecules which constitute the science of chemistry, are all referred in one great whole to this theory of "action at a distance." According to this theory, it is supposed that no rational cause capable of being appreciated by the mind exists or is necessary to explain why one molecule should move towards another; should move from a second, or should be indifferent towards a third molecule. Here the effects are most complicated, and yet take place with the utmost precision and regularity in every instance; in short, it would be difficult to conceive of any case where the presence of a regulating physical agent, or a controlling physical cause, unalterable in its nature, is more needed than here.

The direction of the movement may even be reversed at a certain point of space. Thus, to take the case of the component molecules of a solid for example: then these molecules resist an attempt to separate them, or to move them to a greater distance apart. But when these molecules have been separated, such as when a solid has been broken into two parts, then the molecules resist an attempt to make them approach, or the two parts will not readily unite again by pressure. Hence it must follow from this, as a remarkable fact, that the direction in which the molecules tend to move changes at a particular point of space: the molecules being urged towards each other when placed inside this

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point, and urged from each other (separating) when placed outside this point. If there be no explanation required for this, then one might inquire if there be such a thing as an explanation required for anything.

7. There is another aspect in which this theory of "action at a distance" may be viewed, although we cannot but submit that the above arguments constitute in themselves sufficient and reasonable grounds for the rejection of the theory. However, as we would not neglect any material point that might serve to throw a true light upon the subject, we will, in conclusion, briefly examine the theory of "action at a distance" in connection with the principle of the conservation of energy; it being evident that two principles so intimately connected with the working of physical phenomena must have a direct and important bearing upon each other.

It is an admitted fact that energy is indestructible. For the purpose of practical illustration we will suppose a special case. We may imagine the charged metallic conductor of an electric machine and a pith ball, the arrangement being supposed such that the movement of the ball towards or from the conductor can take place with perfect freedom, or entirely without hindrance, the ball being supposed, by any convenient means, prevented from coming into actual contact with the charged conductor. Then, as is well known, when the conductor is charged, or put in the "electric" condition, the pith ball would be impelled towards the charged conductor, or "attracted." If allowed to come into contact with the charged conductor the ball would be impelled from the charged conductor, or "repelled." It is quite indifferent whether we consider the movement from or the movement towards. We will accordingly take the movement towards, and suppose that the ball is prevented from coming into actual contact with the charged conductor, and therefore tends continually to move towards the conductor.

If, then, we suppose that while the ball is in the nearest proximity to the charged conductor a sharp blow or impulse be communicated to the ball, so as to impart to it a certain initial velocity which would carry it away from the charged conductor, then the ball would rapidly lose the motion imparted by the impulse; the ball would at length come to rest, and would then recoil or return, with freshly acquired motion, towards the charged conductor.

8. Now the question at once suggesting itself would be, how was this motion imparted by the first impulse lost by the ball, or what has become of this motion? If the theory of "action at a distance" cannot account satisfactorily for the disappearance of this motion, then, on this one ground alone, this theory would have to be abandoned, and the necessary inference would at once follow, that since in accordance with the principle of conservation this

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motion lost by the ball cannot have been annihilated, or cannot have gone out of existence spontaneously, that, therefore, this motion must have been transferred to matter; and secondly, therefore, that matter must exist in the vicinity of the ball and electrified conductor.

These two deductions would be absolutely necessary; for, in the first place, in order for the motion given up by the ball to exist, this motion must have been transferred to matter; and secondly, for the motion given up by the ball to be transferred to matter, matter must exist in the vicinity of the ball.

It is unnecessary to add that it is a known fact, that the ether exists in the vicinity of the ball, occupies the intervening space between the ball and charged conductor, and therefore forms a connecting link between the two, the ether even pervading the molecular interstices of both. Moreover, it is a very generally recognized point, that "electricity" must be some form of motion, which motion could not possibly take place without disturbing the ether. However, independently of these considerations, and of the known fact of the existence of the ether, the deduction that matter did exist in the vicinity of the ball, to which the motion could be transferred, would be none the less a necessary one, following directly from the principle of the conservation of energy.

It is important, therefore, to note the intimate bearing which the principle of the conservation of energy has upon the theory of "action at a distance," it being observed that the principle of conservation requires absolutely that matter to which the motion can be transferred must be concerned in bringing the ball to rest; while, on the other hand, the theory of "action at a distance" assumes that matter is not concerned in bringing the ball to rest, so that the principle of the conservation of energy being admitted, the theory of "action at a distance" would have to be abandoned.

9. In preference to taking this plain and straightforward course, however, and then proceeding to investigate the special physical conditions concerned in bringing the ball to rest, the vague theory has been advanced that the energy given up by the ball has assumed a different form which is *not* motion, or the motion lost by the ball has been converted into *something else*, or the motion is said to have been converted into "potential energy," so termed; and further, it is assumed that, although the motion has been transferred to nothing, yet by some unexplained process, on account of the motion lost, the ball has acquired the power of returning by itself to the electrified conductor at any future time, without the intervention of physical agency.

10. Before considering this further, we may just give an illustrative example, serving to show that in a case where the controlling physical conditions are supposed unknown, precisely the same appearances would present themselves as in the case of

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the electrified conductor and pith ball. We may imagine the case of a mass of matter suspended freely, and which tends to approach another mass, under the action of invisible matter in motion, in any form (such as, for example, a concealed jet of air) which impinges continually in the rear of the mass. Then one mass of matter, tending to approach another without a visible cause, the appearance here presented would, therefore, be precisely that of a case where the theory of "action at a distance" is applied, and by applying this theory here (the physical conditions being supposed unknown) the assumption would be, that the tendency exhibited by the mass to approach was due to "attraction." If, in an analogous manner, an impulse be supposed given to the mass in a direction opposite to that in which it tends to move, then the mass rapidly loses the motion imparted by the impulse, comes to rest, and finally recoils or returns, with freshly acquired motion, by the same path. The motion lost by the mass of matter during its recession was transferred to the rebounding molecules of the invisible air-jet; the motion acquired by the mass during its return having been (conversely) transferred from the molecules of the air-jet to the mass.

Here, therefore, it may be observed that precisely the same effects present themselves as in the previous illustrative case of the electrified conductor and pith ball, which exemplifies the general case where the theories of "action at a distance" and "potential energy" are applied. If, therefore, we apply this theory to the case of the mass and air-jet (the physical conditions being supposed unknown), then the assumption would be that the motion lost by the mass during its recession, although not annihilated, and ceasing to exist in the mass itself, was nevertheless not necessarily transferred to anything else; but that this motion took up a different form ("potential energy," so termed), and that thereby the mass of matter acquired the power of recoiling or returning through the same path, without the intervention of physical agency, the something which is *not* motion being assumed to be converted back into motion at the recoil of the mass.

11. If, now, the above theory appear wholly vague and quite inadequate to replace the controlling physical conditions, after these controlling physical conditions have been recognized (as in the above case), then, as a point of principle, the theory can be none the less open to objection in the case of a similar effect, where the existence of controlling physical conditions is not apparent; or, in other words, if the necessity of controlling physical conditions to produce a given physical effect appear obvious, *after* their existence has been recognized, then the necessity for the existence of these controlling physical conditions cannot be less imperative in the case of a similar effect, where their existence is not recognized; and surely it must be an important point to recognize the necessity for the *existence* of a

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thing *before* it makes itself apparent, for this is the sole means whereby the attention can be directed towards its discovery.

12. In fact, this theory of the existence of "potential energy," or an energy *without motion,* in regard to vagueness, cannot be said to differ from the theory of "action at a distance," which it is intended to support, the same system of procedure being adopted, viz. that of assuming a thing to be practicable, where the sole ground upon which the assumption as to practicability can rest—a conception of the means—is wanting. How can it be possible to guard against error, when such a system of procedure is adopted, if, indeed, it be not very like drifting into error? Nothing can be easier than to put forward assumptions of this character, and at the same time nothing is more certain than that there is no teaching of nature, however plain; no truth but what is subject to be disguised by such a system of procedure. The theory, indeed, conveys no definite idea of the nature of the form which the motion is assumed to have taken up.

The very assumption of the existence of energy in a *double* form, or the attempt to attach *two* ideas to the fundamental conception energy, or to assume that *two* kinds of energy exist, cannot but be regarded by itself as sufficiently questionable.

If in the illustrative case of the electrified conductor and pith ball we disregard, as in accordance with the theory, all influence of the presence of the ether or of anything to which to transfer the motion of the ball; then when the ball comes for an instant to rest previous to its recoil, we have only matter at rest and empty space, yet the theory puts forward that the assumed form which the motion has taken up exists here; and further, that this form resolves itself back into motion at the recoil or return of the ball, it being assumed in accordance with this theory that the presence of matter or of a physical agent is not required to transfer the motion to the ball at its recoil.

It would be surely difficult to imagine anything more vague than this, or any assumption or theory where the absence of a reasonable ground or basis to support it is more apparent than in this case; in fact, the theory may be well compared in this respect with the connected theory of "action at a distance," it being also well to observe, as a noteworthy and significant fact, the intimate dependence which exists between these two theories, the abandonment of either involving the abandonment of both.

It is moreover impossible to doubt that the question as to whether these two theories are admissible or not, admits of being finally decided as a point of reasoning, for there can exist but *one* correct method of viewing any subject or question whatever.

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PART II.

SECTION I.

13. We may now enumerate the main physical conditions that would require to be satisfied in order to replace the above theories by physical causes capable of a rational appreciation, and of affording an insight into the mode of working of physical phenomena.

As a first condition, we require the existence of a physical agent capable of transmitting motions to a distance with speed and facility, in order to refer to physical agency all the effects at present brought under the theory of "action at a distance." As a second condition, this physical agent must be shown to be capable of enclosing a store of motion of a very intense character, competent to produce all those forcible molecular and other movements of matter exhibited in such effects as the phenomena of chemical action, the "electric" motions, combustion, the remarkable development of molecular motion observed in the case of explosive compounds, such as in the explosion of gunpowder, and other numerous and striking phases of motion witnessed on all sides. Thirdly, this physical agent will have to be proved to be competent to exert an intense pressure upon the molecules of matter, as consonant with the very forcible character of the static effects exhibited in "cohesion," and the stable aggregation of molecules generally: and finally, these several physical qualities of the agent will have to be shown to be capable of existing harmoniously together and consistent with an extremely low density in the agent.

14. *Physical Constitution of the Ether.*—The ether being the means by which the entire energy received from the sun in the form of heat and light, &c., is transmitted to the earth, the ether therefore may be properly regarded as the most important of physical agents; this agent being a most influential one and everywhere present, to the ether therefore we must look as the agent concerned in the various molecular and other movements of matter, including the physical effects produced at a distance generally.

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15. Now in dealing with the problem as to the physical constitution of the ether, or the physical basis upon which its qualities depend, it may be shown as a noteworthy point that if we exclude the theory of "action at a distance," and consequently the theory of "potential energy," then this physical problem will admit of only *one* solution, or the problem admits of being solved but in one special way. This point is one of importance and interest, since if it be recognized that reasonable grounds exist for rejecting the above theories, then the deduction would follow with certainty that this solution to the problem is the true one or the actual fact, this following necessarily from the circumstance of the existence of but one solution.

To those who are not prepared to reject the theory of "action at a distance" on purely abstract grounds, the simple course lies open of putting the results necessarily attendant on this solution to the problem to the test of observed facts. Even if merely for the sake of argument we put for an instant the question as to the admissibility of the theory of "action at a distance" out of sight altogether, it cannot but be regarded as a point of interest that by the rejection of this theory but one solution to the problem should exist, and therefore that if this theory be unfounded, this solution to the problem must be the true one.

16. On the other hand, it may be shown that if the theory of "action at a distance" be admitted, then a final solution to the problem is no longer possible, from the fact that no definite limit exists to the number of assumptions or possible solutions, and therefore it becomes impossible to fix finally upon any one, since the same end might be attained in a great variety of ways. This will become apparent after the question has been examined.

Thus in the first place it would be impossible to decide the fundamental question whether the normal state of the component particles of the ether is a state of motion or a state of rest; for by the hypothesis of non-material agencies, the particles might be at rest and yet be capable of expanding the agent and producing physical effects of pressure, &c. If it were assumed as a mere hypothesis that the particles of the agent were in motion in their normal state, then it would be impossible, by the admission of the theory of "action at a distance," to fix finally upon the character of this motion; for it is evident that the particles might be either moving in straight lines, or in curved paths whose character would depend on the values or intensities assumed to the non-material agencies in different points of space, i.e. dependent on the assumed mode of variation of the intensity of the agency by a change of distance of the particles, which mode of variation the theory of "action at a distance" assumes to be purely arbitrary, or it might vary as the distance, as the square of the distance, &c.

If, again, the inquiry were directed as to the cause producing the remarkable elasticity of the ether, a fact proved by the speed

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with which this agent can propagate waves, such as waves of light, then a final solution to this question would be equally impossible, for it would be impossible to decide whether to refer the elasticity of the agent to a motion of its component particles or not, since, in accordance with the theory of "action at a distance," the particles might be at rest and yet produce any degree of elasticity; and if in motion there is scarcely an assignable limit to the variety of motion. In short, the practically unlimited field for speculation which this theory brings with it precludes the possibility of a final decision, and the maze of hypotheses presented by it renders theoretic reasoning of little avail.

17. If, on the other hand, we reject the theory of "action at a distance" and the connected theory of "potential energy," then a definite course lies open. Considering first the question whether the normal state of the component particles of the ether is a state of motion or a state of rest; then it may be shown that taking the observed fact of the elasticity of the ether, it admits of being deduced from the principle of the conservation of energy that the normal state of the ether particles is a state of motion.

18. If any portion of an aeriform medium, such for example as a portion of air be supposed confined within a receptacle which is not rigid, then the quality of elasticity enables the mass of confined air to expand when the outer air pressure is in any way removed, in which act of expansion motion is communicated to the sides of the receptacle, which yield to the internal pressure. The quality of elasticity in an aeriform medium, therefore, enables it under certain conditions to communicate or develop motion. Now it follows from the principle of conservation that the previous existence of motion is the absolutely essential condition in order for motion to be developed, for unless motion previously existed, motion could not be expended in the act of developing motion (as in the act of expansion of a gas), but this is an absolutely necessary condition, for otherwise the sum of energy could not remain constant, but there would be a creation of motion out of nothing. The quality of elasticity, therefore, in an aeriform medium by which it can expand and fill a larger portion of space than it occupies under normal conditions, and in which act motion is developed, must be dependent on a motion previously existing. Hence, since it is an observed fact that the ether possesses in its normal state the quality of elasticity, the inference necessarily follows that the normal state of the ether particles must be a state of motion.

19. We have next to inquire as to the mode or character of this motion. It is an admitted self-evident principle that a mass of matter is incapable of itself to change the direction of its motion. Absence of change in direction being the characteristic of the straight line; it therefore follows that a mass or particle of matter

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moving in absolutely free space, and unobstructed by other matter in any form, will continue to move in a straight line until by encountering matter in some form its direction of motion may be changed. From this the inference necessarily follows that the ether particles move in straight lines.

20. The only remaining question is as to the general direction of the motion. Now, it is at once clear that this motion must take place in such a way that when any appreciable portion of the medium made up of a large number of particles is considered, this portion of the medium can, as a whole, maintain a fixed position, or can be in equilibrium of pressure with the surrounding medium. Now, this maintenance of a fixed position by the portion of the medium or the maintenance of an equilibrium of pressure on all sides can evidently only be satisfied on the condition that the particles are moving in every possible direction, and not in any one particular direction in preference to another, the particles continually interchanging motion or rebounding from each other in every direction, and thereby propagating an equal pressure on all sides.

There would obviously be no reason why the particles should be moving in one direction more than in another; and, moreover, it may be shown that there exists a special self-acting tendency for this motion of the particles to be maintained towards every possible direction. This results from the consideration that the equilibrium of pressure depends on the fact that the motion takes place towards every direction, and a motion of any notable number of particles towards one special direction would necessarily cause a disturbance of the equilibrium of pressure, and this, by causing a yielding of the medium in the direction of the greatest pressure, would speedily cause a readjustment of the pressure; and since this irregularity of pressure is necessarily self-righting, the irregularity of the motion of the particles on which the pressure depends must also be self-righting, equilibrium of pressure being only restored when the irregularity of motion has corrected itself, i. e. when the motion of the particles takes place towards all directions.

The existence of this mechanical self-adjusting tendency will be very apparent if we consider any special case whatever. Thus, supposing, merely for illustration, the component particles of a single cubic foot of the medium to be all moving at a given instant in one common direction, then by this procedure the transverse pressure exerted by this cubic foot of the medium would cease, for a pressure evidently cannot be exerted at right angles to the direction of motion. The pressure of the surrounding medium would therefore cause this cubic foot of the medium to collapse laterally (due to the absence of a lateral opposing pressure), and in this act the particles of this cubic foot of the

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medium would receive a forcible transverse acceleration, which they previously wanted, the abnormal movement being thus soon corrected and the equilibrium of pressure restored. It is clear that in the actual fact no notable irregularity in the motion can accumulate, for the rapid interchange of motion going on among the particles necessarily corrects the slightest disturbance of the equilibrium of pressure immediately on its occurrence, a continual self-acting adjustment thus going on, which entirely prevents an abnormal movement of the particles from developing itself.

21. To summarize therefore: the inferences are, *first, that the normal state of the component particles of the ether is a state of motion; second, that this motion of the particles takes place in straight lines; and third, that this motion takes place towards every possible direction.* This deduction as to the physical constitution of the ether, to which we have been led without choice, since (the theory of "action at a distance" being excluded) the problem admits of but *one* solution, resembles in its nature the theory applied by Joule and Clausius to gases. This theory would accordingly have a general application, or would be applicable to all aeriform media, one apparent point in the theory being its extreme simplicity. We may note, that since when the medium is in its normal state the motion of the component particles takes place towards every possible direction, the particles would therefore be accelerated and retarded both in transverse and in longitudinal directions at the passage of waves.

22. The fact of the continuance of the motion of the ether particles without decrease or loss becomes very apparent when it is considered that one particle could only lose its motion by transferring that motion to another.

The fact that a mass of matter will remain in motion until acted on by a physical cause appears sometimes to be regarded as a less self-evident truth than the fact that a mass of matter will remain at rest until acted on by a physical cause; but it may be shown that the two cases are equally axiomatic, for a change from any given degree of motion to rest is precisely the same change (though inverse) as a change from rest to that same degree of motion. Hence if it be looked upon as self-evident that a mass of matter will not of itself change its state from rest to motion, then, to be consistent, it must be looked upon as equally self-evident that a mass of matter will not of itself change its state from motion to rest, or the mass is wholly incompetent to change its state at all.

23. It is a known fact that the quality of elasticity is developed in the ether to a high degree: hence it would be reasonable to expect from this that the motion upon which this elasticity depends must be an extremely rapid motion. The inquiry therefore suggests itself, whether there is any observed fact that would indicate the value of this motion, or the mean speed of the ether particles in their normal state.

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Now the velocity with which the ether transmits a wave or impulse has been measured, this velocity being about 190,000 miles per second, in round numbers. The speed with which a small impulse can be conveyed from particle to particle in the normal state of the ether must clearly depend on the speed with which an interchange of motion can effect itself between the particles, i. e. must depend on the normal speed of the particles themselves. Hence the deduction follows that the normal velocity of the ether particles must at least equal that with which they can transmit a wave (such as a wave of light), for on no other physical condition could any change of velocity in the ether particles, however slight, produced by some disturbing cause, be propagated to a distance from particle to particle at the above velocity; indeed, it is necessary to infer that the actual normal velocity of the particles must be somewhat in excess of the above, since the wave is not transmitted by particles which are all moving in the direct line of propagation of the wave, but also by particles which are moving obliquely. The wave could evidently be transmitted forward at a speed equal to that of the particles themselves, only on the condition that they were all moving in the direct line of propagation of the wave, which is not the fact.

This resembles the parallel case of an air wave (such as a wave of sound), which is transmitted at a slower rate than the mean velocity of the air molecules in their normal state, for this velocity has been fixed at about 1600 feet per second, while the velocity of propagation of a wave, such as a wave of sound, is less than this, or about 1150 feet per second.

24. The above limiting value for the normal velocity of the ether particles will probably appear inordinately high on the first consideration of the subject; but it is essential that the special circumstances of the case should be taken into account. Thus, owing to the extreme minuteness, or very small mass, of the ether particles as compared with gross molecules, the absolute value of the energy possessed by each ether particle, even when moving at the above velocity, may be extremely small, and may possibly be even less than the energy possessed by an air molecule when moving at its normal velocity; for there is no limit to the extent to which the energy possessed by each particle may be conceived to be reduced by a sub-division of the matter of which the ether consists, and yet this does not detract in the least degree from the total sum of energy. The molecules of gases are known to possess a higher normal velocity as the molecular density diminishes. The exceptionally low density of the ether would rather lead a high normal speed for the particles to be expected than otherwise.

An extensive state of subdivision would also have the effect of so curtailing the mean length of path of the particles, or of restricting the distances which the particles can move before being intercepted by other particles within such narrow limits, as effec-

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tually to conceal the existence of this motion from the direct evidence of the senses.

25. The above deduction, as to the high speed of the ether particles in their normal state, throws at once a light upon the existence of a vast store of energy in space of a very intense character, competent to produce the most forcible observed molecular motions, such as the phenomena of chemical action, combustion, the explosion of gunpowder, and other remarkable cases of the development of motion or work, all such effects finding their explanation in an interchange of motion between the ether and the molecules of matter under special conditions, which we shall have to consider farther on. The special physical qualities of the ether may be shown to render it an agent admirably adapted, in a mechanical point of view, to fulfil its varied functions, or it may be properly contemplated as a piece of mechanism specially adapted to its work.

26. In considering the high normal velocity of the ether particles, it is to be expected beforehand that this agent must exert an extremely forcible pressure upon the molecules of matter, even if every allowance be made for the extreme low density of the agent; for it is important to note that the pressure exerted is as the square of the speed of the particles of the agent, and therefore the pressure rises in a very rapid ratio as the speed increases; so that taking into account this fact, in conjunction with the high velocity of the particles, we must be prepared to find this pressure will have a very high value. In looking to physical phenomena for an indication of this pressure, and also with the object, if possible, of arriving at a limiting value for its intensity, or the value which this pressure must at least attain on the lowest computation, we will consider one observed fact.

27. Steel of the best quality, in the form of fine wire, has been known to bear a tensile strain represented by not less than 150 tons per square inch,* and even this cannot be said to be the limit to the tensile strength of steel, since the tenacity obtainable increases as the diameter of the wire is reduced.

We will consider the case when a strain is applied to such a wire until rupture ensues; then it is necessary to conclude that the molecules of the wire are, before the strain is applied, at a certain distance from each other, for the wire can contract sensibly by a change of temperature. If, therefore, these molecules were surrounded by absolute empty space, there would be no conceivable physical cause why they should resist an attempt, however feeble, merely to change their positions in space; but it is scarcely necessary to add that the molecular interstices of the wire, as is the case with matter generally, are necessarily pervaded by the ether, which

* For a special example, see 'Telegraphic Journal' (May 1, 1874). The tenacity of the wire in question (No. 22 B.W.G. diam. = 0·03 inch) might have been increased, had pliability been no consideration.

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exercises its pressure upon the molecules of the wire, which molecules are also in a state of energetic vibration, as indicated by the forcible ether waves emitted (radiation of heat). The ether therefore which pervades the wire cannot but be disturbed by the movement attendant on the separation of the molecules of the wire, and is the one agent to which the forcible resistance encountered in separating these molecules can be referred.

In order to view the subject in its simplest form, we will only regard two transverse layers of molecules forming the cross section of the wire; or we may even imagine, merely for the purpose of illustration, two such layers to have been separated from the wire, and that now a strain is applied in order to separate these two layers of vibrating molecules from each other. Then the deduction follows as a necessary one, that when by the action of the applied strain the distance of these two layers of vibrating molecules has been increased, that this change of distance has brought about a change in the distribution of the ether pressure, or has disturbed the equilibrium of this pressure, such that when the resistance has attained a maximum, a reduction of the ether pressure upon the adjacent halves of the component molecules of the two layers, amounting to 150 tons per square inch, has been effected, so that the normal ether pressure upon the outer halves of the molecules forming the two layers tends, with the above force, to resist the separation of the molecules.

As to the precise physical process by which a reduction of the pressure of the intervening medium can take place in the presence of vibrating matter, we shall reserve the consideration of this point for the present; but it may be noted that the inference is none the less essential, that a reduction of the ether pressure does take place in the presence of the opposed vibrating molecules of the wire, since there remains no other conceivable means of explaining in a realizable manner why these portions of matter (molecules), already completely disconnected from each other in the normal state of the wire, should require this enormous force to shift their positions in the act of breaking the wire, unless in this act there were something further to be accomplished than merely to change the positions of the molecules in space.

28. Now it is to be observed that the above illustrative case only gives the amount of the reduction of the ether pressure, or the difference of pressure upon the opposite halves of the molecules, and not the total or normal ether pressure, which is the point we are investigating, and it might well be that this difference of pressure only amounted to a small part of the total ether pressure.

That this difference of pressure is far from representing the total ether pressure is shown by a consideration of the case of chemically combined molecules, the force required to separate molecules "chemically combined," as it is termed, being, as a

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known fact, very much greater than in the case of "cohesion," so termed; indeed it is impossible by ordinary mechanical means to separate chemically combined molecules, whereas this result is attainable with comparative facility in the case of "cohesion." The very much greater intensity of the force that would be required to separate chemically combined molecules is well shown when the converse process takes place. Thus the explosive energy and intense heat developed at the approach of oxygen and hydrogen molecules, when the mixed gases are detonated, clearly shows the high intensity of the force that would be required to separate these molecules from each other, thereby showing the high intensity of the controlling ether pressure, and indicating that the difference of pressure to be overcome in separating the molecules in this case must be many times greater than in the case of "cohesion," as in the example given of steel. If we suppose the intensity of the pressure to be overcome in the case of the separation of the molecules of oxygen and hydrogen, one of the most powerful cases of chemical union, to be only three times greater than that overcome by the separation of the molecules in the example given of the steel wire, then this would give 450 tons per square inch as the difference of pressure effective in the case of the molecules of oxygen and hydrogen.

This is, however, not the total or normal ether pressure, but only the effective difference of pressure; however, as our object is only to arrive at a limiting estimate for this pressure, or to fix upon the lowest value consistent with what observed physical facts would require, we will accordingly take in round numbers the estimate of 500 tons per square inch as a limiting value for the ether pressure, having thus valid grounds for concluding that this estimate is within the facts as they actually exist.

We might have noted in the example given of the steel wire that there are lateral interstices between the molecules, so that the entire estimated cross section of the wire is not available, and therefore for this cause the difference of ether pressure effective in this case must have been to a certain extent underrated.

29. We are prepared for the above estimate as to the value of the ether pressure being received with a certain amount of incredulity, at all events at the outset; indeed, the existence of such an intensity of pressure as this may well be sufficient at the first thought to strike one with astonishment; but it is to be noted that, however great this pressure might be, it could not make itself palpable to the senses, for since the ether penetrates the molecular interstices of matter, its pressure is equalized on all sides. The air cannot penetrate with freedom the molecular interstices as is the case with the ether, yet a pressure of the air amounting to several tons on the human body can exist without the perception of the senses; how much more cause, therefore, is there for the perfect concealment of the existence of the ether

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pressure, which is exercised against the molecules of matter themselves, a perfect equilibrium existing? It is therefore certain beforehand that the mere evidence of the senses cannot affect this question at all.

From purely *à priori* considerations the existence of a high pressure cannot be said to be less likely than a low pressure, or indeed any one particular value for the ether pressure be said to be more probable than another. In the object, therefore, to arrive at an estimate or limiting value for this pressure, we must consider solely observed physical facts, and be guided thereby.

It will be found that after the problem has been considered in its other aspects, and the special functions of the ether in physical phenomena have been taken into account and weighed, the more apparent will become the mechanical fitness of this high pressure, whereby this great physical agent is adapted to act forcibly upon the molecules of matter; whether it be to control these molecules forcibly in stable equilibrium, as illustrated by the stable aggregation of molecules in "cohesion," "chemical union," &c. (i. e. the general phenomena of the aggregation of molecules); or to produce forcible dynamic effects when the equilibrium of pressure is disturbed, as illustrated by the forcible movements of the molecules of matter exhibited in the varied phenomena of chemical action, combustion, the effects of explosives, &c.

30. *Density of the Ether.*—It is a known fact that the density of the ether is very low, this agent being thus suited to afford free passage to cosmical bodies travelling at high speeds, the planets, &c. In order, therefore, to be consistent with observed facts, it will be essential to show that the existence of the high static pressure as above deduced is compatible with the low density of the ether.

Though pressure is due to motion, we use the term "static" pressure for convenience, and in the same sense as it might be applied to the pressure of a confined gas, due to the motion of its molecules.

31. The mean density of the air at the earth's surface is known, and the normal velocity of the air molecules giving a pressure of 15 lb. per square inch has been deduced as 1600 feet per second, in round numbers. The pressure of the ether as of any aeriform medium being proportional to the square of the velocity of the component particles, and in the ratio of the density: taking, therefore, as previously, the measured speed of a wave of light as the lowest limit for the speed of the ether particles, we will, in the first place, consider what the density of the ether would be if it only gave a pressure equal to that of the atmosphere. It is evident, therefore, that in order for the ether to produce a pressure equal to that of the atmosphere, the ether density would require to be so much less than the atmospheric density, as the square of the

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normal velocity of the ether particles is greater than the square of the normal velocity of the air molecules. Taking, therefore, the square of the velocity of the ether particles (in feet per second), and dividing it by the square of the velocity of the air molecules (in feet per second) we have $\frac{(190000 \times 5280)^2}{1600^2} = 393{,}120{,}000{,}000$, or this result expresses the number of times the ether density would require to be less than the atmospheric density, in order for the ether to give a pressure equal to that of the atmosphere (15 lb. per square inch). This density expresses such an infinitesimal amount or almost vanishing quantity, viz. a density upwards of three hundred and ninety thousand millions of times less than that of the atmosphere, that the result can scarcely but be regarded as a fiction; indeed, a bare consideration of the result by itself would almost warrant the inference that the ether pressure must be a considerable multiple of the atmospheric pressure, if only to bring up the ether density to a reasonable amount.

32. We will, accordingly, now take the value for the ether pressure (500 tons per square inch) previously fixed upon as the lowest limiting value, and we may then deduce what the density would amount to, in order to give this pressure. Pressure being directly proportional to density, the above value for the ether density corresponding to a pressure of 15 lb. per square inch would therefore, to give a pressure of 500 tons per square inch, have to be increased in the ratio of these pressures: or we have $\frac{1}{393{,}120{,}000{,}000} \times \frac{500 \times 2240}{15} = \frac{1}{5{,}264{,}800}$, or this result indicates that the density of the ether giving a pressure of 500 tons per square inch, would only amount to $\frac{1}{5264800}$ part of the density of the atmosphere. This value for the ether density, being upwards of five million two hundred thousand times less than the atmospheric density, represents a density so insignificant as to be less than that of the best gaseous vacua, for this ether density corresponds to a rarefaction of the air carried to $\frac{1}{172000}$ of an inch of mercury. If we take a fairly good air-pump vacuum at $\frac{1}{100}$ of an inch of mercury, then this ether density represents a rarefaction carried 1720 times farther.

Hence we may observe, therefore, the perfect mechanical possibility of the existence of a very forcible ether pressure, consistent with the known fact that the density of the ether is extremely low; a pressure of an intensity adequate to account for the stable and forcible character of the effects exhibited in the phenomena of "cohesion," and the general phenomena of the aggregation of molecules, which may be classed under the "static" effects of the ether; as the other physical effects, such as the general phenomena of chemical action, combustion, &c., may be classed under the "dynamic" effects of the ether. The fact that pressure increases in the rapid ratio of the square of the speed of the

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particles of the agent is a most important one, as this renders possible the attainment of a very forcible pressure with the aid of but a small quantity of matter whose normal velocity is a high one.

33. In connection with this subject, it may be of interest to contemplate the possibility of the following as a physical problem. If we suppose a given mass of matter and a given volume of space, the volume of the space being supposed vastly greater than that of the mass of matter. Then it becomes possible, by the subdivision of this mass of matter (which may be readily conceived to be carried out to any extent), to pervade the entire volume of the space with matter, or there is no limit to the degree of close proximity into which the particles of matter pervading this volume of space may be brought by continued subdivision, the approach of the particles going on continuously without limit as the subdivision progresses. Thus, with a given mass of matter there is no limit to the extent of space that may be pervaded by matter by continued subdivision, or there may be no appreciable portion of the vast volume of space but what contains myriads of particles of matter. The normal state of this finely subdivided matter may be conceived to be a state of motion or a state of rest; if a state of motion, then we may observe the physical possibility of the existence of a store of energy of an extreme intensity, and which, from the minuteness and small length of path of the moving particles, must be concealed; this motion being also necessarily attended by the production of an intense and at the same time evenly balanced pressure, the smoothness and uniformity of the pressure, and the consequent concealment of its existence from the senses, being more and more complete as the subdivision progresses.

34. Many considerations point to the conclusion that the state of subdivision in the case of the ether is extreme, or that the ether particles are incomparably more minute than the molecules of matter. In the first place, the ether could not well otherwise penetrate with facility the molecular interstices. Secondly, the known fact that the density of the ether is very low, points to the conclusion that the ether particles are very minute, for if this were not the case, the mean distance of the particles would necessarily be inordinately great. Now, the observed extreme steadiness of the effects due to the ether pressure, as exhibited in the phenomena of "cohesion," &c., makes the inference necessary that the mean distance of the ether particles cannot be great, but that the mean distance of the particles is probably contained many times within the limits of space which a molecule of matter would occupy, and that, therefore, so much the more must the particles themselves be small compared with molecules.

It is clear that if the mean distance of the ether particles bore any near proportion to the dimensions of molecules, then the number of particles impinging against the molecule would neces-

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sarily fluctuate or vary considerably at each instant, which would be quite incompatible with the maintenance of a steady pressure against the molecule. The mechanical condition required for the maintenance of a steady and constant pressure against a surface must evidently be that the number of particles impinging against the surface is on an average the same at each instant, and this condition can only be fulfilled when the mean distance of the impinging particles is small relatively to the extent of the surface, and the number of the particles is therefore great; just as, for example, the force with which two hemispherical cups, when evacuated, are pressed together by the impacts of the air molecules upon their outer surfaces, could not possibly be steady and constant, if the mean distance of the air molecules were not incomparably less than the dimensions of the surfaces against which they impinge. The same considerations precisely in principle apply in the case of the action of the pressure of the ether upon molecules, or the mean distance of the ether particles must, to render possible the maintenance of a steady pressure, be much less than the dimensions of molecules. If, therefore, the mean distance of the ether particles be small compared with the dimensions of molecules, how much more must the particles themselves be small compared with molecules, and this more especially since the known low density of the ether renders the inference necessary that the dimensions of the ether particles must be small compared with their mean distance? Analogy would also be in favour of the above conclusions, for just as the mean distance of the air molecules is extremely small compared with the length of a wave of sound, so the mean distance of the ether particles is extremely small compared with the length of a wave of light. This extreme minuteness of dimensions is at the same time the fitting mechanical condition adapted to a high speed for the particles, as by this extremely subdivided state of the matter forming the ether, the energy almost vanishes as regards each ether particle taken separately, and yet subsists as a whole to its full value; or by this minuteness of the particles or extensive state of subdivision, the motion goes on, as it were, so smoothly and equably as to be imperceptible, and the equilibrium of masses and molecules of matter (excepting under special conditions) is not disturbed thereby.

35. Let us suppose, for the purpose of illustration, that it has been possible to form an air vacuum corresponding to $\frac{1}{172000}$ of an inch of mercury. Then the amount of air thus left in the receiver, or the sum of the masses of the residual air molecules, would equal the sum of the masses of the ether particles, or the quantity of matter represented by the ether contained within the same receiver, this being in accordance with the limiting value for the ether density already fixed upon. Now the matter represented by these air molecules contained within the receiver when

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compared with the equal quantity of matter in the form of ether contained within the same space, represents, on the one hand, a few extremely large masses of matter possessing an extremely slow speed; on the other hand, a large number of extremely small masses of matter possessing a very high speed.

If now we imagine, merely for illustration, each of these air molecules to be subdivided into a million parts, and that the speed of each component part has been increased a thousand times. The presence of the ether within the receiver may be left out of account for the present. Then by this imaginary process of subdivision, the mean distance of these parts of matter (which we shall term "particles") would be so reduced as to bring these particles into closer proximity than the molecules of air outside the receiver (the mean distance of the particles of the subdivided matter being inversely as the cube root of their number). The pressure against the interior of the receiver, which is as the square of the speed of the particles, would now be increased a millionfold; and yet this result is attained without any increase in the absolute value of the energy of each particle, for the energy has, by the reduction of mass, remained precisely the same for each particle as before, although the total energy has become vastly greater, this energy being now subdivided among a large number of particles, and the pressure maintained by a greatly increased number of moving particles.

We might imagine this process of subdivision, or this reduction of mass combined with increase of speed, to go on progressively, and thus the total energy would be continually increasing, and the mean distance and mean length of path of these small moving masses or particles would be continually diminishing, and therefore the concealment of this motion from the senses would be more and more complete. The pressure would continually rise in intensity, and at the same time become more even and perfectly balanced as the number of particles increased.

We might thus imagine this process to go on progressively, until at length the dimensions, mean distance, and speed of the ether particles themselves had been reached; or it is possible thus step by step to arrive at a just conception of the wonderful intensity of the store of energy that is rendered physically practicable, and the high static value of the pressure that may be reached, under the simple mechanical conditions of an extensive subdivision of matter combined with a high speed.

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SECTION II.

36. *Propagation of Waves.*—We have now to consider briefly, in general principle, the mode or physical process by which variations of velocity produced in the particles of an aeriform medium, including those periodic increments and decrements of velocity termed "waves," are propagated to a distance by the medium.

We may, as an illustrative example, take the case of a tuning-fork vibrating in air. Then it is to be noted that before the prong is put in motion the air molecules are already in motion (having a speed of about 1600 feet per second), rebounding from the prong in all directions and exerting an equal pressure.

Then, after the fork has been put in vibration, if we regard one forward movement or semivibration of the prong, then the rebounding air molecules being struck by the prong, receive an increment of velocity (small compared with their normal velocity). This increment of velocity is instantly transferred to the neighbouring air molecules in the collisions (mutual exchange of motion) continually occurring; this transference of motion from molecule to molecule taking place in accordance with the simple principles of impact in the case of equal masses. The air molecules next the prong, therefore, lose their increment of velocity by transferring it to the molecules in advance, the molecules returning to the prong with their normal velocities to receive a fresh increment, which they again transfer, &c.; and thus during the advance of the prong a succession of small increments of velocity is imparted to the air molecules in the form of a pulse or wave, which is transmitted through the air by exchange of motion with a velocity dependent on the normal velocity of the air molecules. Since the air molecules forming this pulse or half of the wave possess, during the interval occupied by the passage of the pulse, a velocity slightly in excess of that of the molecules around them, this portion of the wave is somewhat pushed forward, and a "condensation" is the result of the increment of velocity.

We have up to this point regarded one forward movement or semivibration of the prong: the latter gradually comes to rest before commencing its backward movement, and thus the first part of the wave is succeeded by a portion of air whose molecules have received no perceptible increment of velocity. On the prong commencing its backward movement to finish one complete vibration, the impinging air molecules now striking against its receding surface lose a portion of their normal velocity by transference to the prong, the decrement of velocity thus sustained by the air molecules being transmitted in precisely the same manner by

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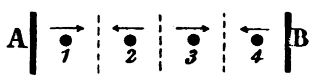
exchange of motion from molecule to molecule through the surrounding air; and since the air molecules forming this portion of the wave possess during the passage of the wave a velocity slightly less than that of the molecules in the advanced part of the wave, the mass of air is accordingly shifted backwards in relation to the advanced part of the wave, a "rarefaction" being the result.

37. The principle involved admits of further illustration from a somewhat different point of view. Since the condition for the equilibrium of pressure of an aeriform medium requires that the particles should not be moving in one special direction in preference to another, but in every possible direction, it follows, therefore, that if any imaginary straight line be taken in an aeriform medium, such as the ether for example, then since the particles are moving in every possible direction, and the medium is in equilibrium of pressure along this line (as in every direction), there must therefore be at any given instant, when a large number of particles are taken, on an average as many particles whose direction of motion is towards one extremity of the line, as there are particles whose direction of motion is towards the opposite extremity, the resolved components of the motions in the direction of the line being taken when the motions are oblique; for evidently, in order that equilibrium of pressure may exist, or in order that the particles in their mutual interchange of motion may balance each other's effects, as many particles must be moving in any one given direction as in the opposite.

The principle involved in the movement admits, therefore, of being illustrated in a very simple manner; and as regards method of illustration we are to a certain extent indebted to a paper by Waterston, 'On the Theory of Sound;'* this paper treating specially of the mode of propagation of waves by the air molecules, whose normal motion is considered to take place in accordance with the theory of Joule and Clausius. Let us suppose a line or row of spheres 1, 2, 3, &c. (Fig. 1), of which as many at any given instant are moving towards one extremity of the line as towards the opposite; or we may suppose all those spheres designated with the odd numbers to be moving simultaneously in one direction, while those designated with the even numbers are moving simultaneously in the opposite direction. The motion of the spheres may be supposed to take place without resistance, and so to go on continuously; the row of spheres being further supposed as placed between two plane surfaces A and B, from which the end ones rebound, the whole line of spheres being thus in equilibrium and exerting by their impacts a pressure tending to separate the controlling surfaces A and B. Each sphere, therefore, performs a simple reciprocating

Fig. 1.



* 'Philosophical Magazine,' Jan., 1859, Supp. to vol. xvi.

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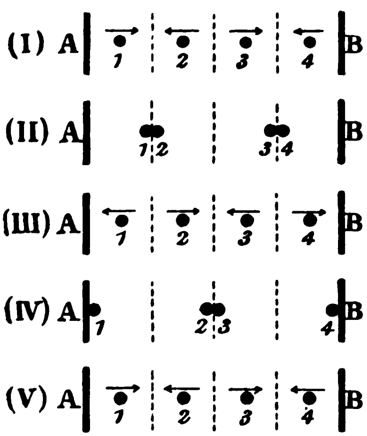
movement within the space bounded by the dotted lines in the diagram, the spheres continually coming into collision or rebounding from each other; one half their number, represented by the odd numbers (i. e. one half the total mass of matter forming the row of spheres), moving simultaneously in one direction, during the time that the other half, marked with the even numbers, moves in the reverse direction, the whole line of spheres being thus in perfect equilibrium, and not tending bodily as a whole to move in any particular direction, but simply tending to open out or expand, and to separate the controlling surfaces A and B.

This it may be observed is the only mode of motion possible to the spheres by which equilibrium can be maintained; in fact, this constitutes in principle the only mode of motion possible to matter by which it can be in rapid motion, and yet, regarded as a whole, can maintain a fixed position; for an oscillatory movement is the only means by which a mass can be in motion and yet not deviate from a given spot; and the movement of an equal quantity of the matter in any two opposite directions is the only means by which equilibrium can be maintained, the two moving portions thus precisely balancing each other's effects; this being the case with particles of an aeriform medium, which move in such a way that at any given instant along any imaginary straight line in the medium there are on the whole as many particles moving in one direction as in the opposite.



In the diagram, I. II. III. IV. V. may serve to represent different phases of the movement. It is, of course, clear that in the actual fact the motions and collisions of the particles of an aeriform medium would be oblique and irregular along such an imaginary line; but since the particles maintain an equilibrium by their collisions when a sufficient number are taken into account, the principle involved in the movement cannot therefore be at all affected by making the motions regular; and the mode of illustration, as shown in the diagram, will therefore serve to give a perfectly just idea of the principle involved, and to show the mode in which waves are propagated.

38. We will suppose now that a forward and backward motion is communicated to the plane A, in the form of a vibratory movement; also the line of spheres may be supposed to be extended indefinitely from the plane A, the movement of vibration of the plane being also supposed slow, compared with the normal velocity

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of the spheres. In that case the sphere 1 would strike against the plane A a number of times during one forward movement or semivibration of the plane. On the commencement of the first forward motion of the plane, the plane moving towards the sphere 1, the latter receives a small increment of velocity, which it transfers at the collision to sphere 2, the two spheres simply exchanging velocities. The sphere 1, therefore, returns to the plane with its original normal velocity unchanged, and receives a second similar increment of velocity from the plane, which it again transfers, &c. The sphere 2 at once transfers to sphere 3 the increment of velocity received from sphere 1, the sphere 2 returning with its normal velocity to repeat the process. In this way, during one forward movement or semivibration of the plane A, a series of small, successive increments of velocity are propagated in the form of a pulse, by exchange of motion along the line of spheres, the velocity of transmission of the pulse being that of the spheres themselves, or the velocity of transmission is equal to the normal velocity of the spheres. The length of this pulse or semiwave evidently must depend on the time taken by the plane to complete a semivibration, or wave length is proportional to vibrating period. The wave length will also evidently depend on the normal velocity of the spheres.

These points are practically illustrated in the case of gases, or aeriform media generally, the different rates of transmission of waves (waves of sound, for example) by various gases being proportional to the different normal speeds of the component molecules of the gases. The molecules of hydrogen have a normal speed about four times greater than the molecules of air, and waves (such as waves of sound) are transmitted by hydrogen at a speed about four times greater than in the case of air; also a wave due to a given vibrating period, when generated in hydrogen, is about four times longer than when generated in air.

39. Returning to our illustrative case. The pulse due to the forward motion of the plane A being made up of a succession of spheres, moving (at the time of passage of the pulse) with a velocity slightly in excess of the normal velocity of the spheres forming the advanced portion of the line, this portion of the wave, or the spheres forming it, would therefore be slightly shifted forwards, producing a "condensation."

The plane comes to rest gradually before changing the direction of its motion; and the opposite movement is also commenced gradually, the motion of the plane being therefore almost nothing for a short interval, so that the first portion of the wave is separated from the second by a succession of spheres whose normal velocities have not been appreciably changed, an effect corresponding to the normal mass of air which separates the two portions of a wave of sound.

By the backward movement of the plane at the next semi-

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vibration, a series of small decrements of velocity, forming the second half of the wave, is transmitted in the same manner along the line of spheres; and the velocity of the spheres at the instant when this portion of the wave passes them, being slightly less than the normal velocity of the adjacent spheres, this half of the wave, or the spheres forming it, are therefore shifted backwards in relation to the advanced portion of the wave, an opening out of the line of spheres, or a "rarefaction," being the result. It is clear that in the actual fact in the case of an aeriform medium, since the motions of the particles take place also obliquely to the line of propagation of the wave, the rate of propagation cannot therefore equal the normal speed of the particles, but must be to a certain degree slower. This, however, does not affect in the least the principle involved, and, accordingly, the above mode of illustration will serve to convey a perfectly just idea of the mode of the normal motion of the component particles of an aeriform medium, and the physical means by which through this mode of motion "waves," or any changes of velocity experienced by the particles, are propagated to a distance along the medium.

SECTION III.

40. *The Phenomena of "Attraction" and "Repulsion."*—In returning to the consideration of the phenomena of "attraction" and "repulsion," we may first give some quotations from some papers contained in the 'Philosophical Magazine' (November, 1870; June, 1871), descriptive of experiments with masses of matter vibrating in air (tuning-forks, &c.), these experimental results being illustrative of the power of vibrating masses to disturb the equilibrium of pressure of the intervening medium, attended by the effects of attraction and repulsion.

These phenomena appear to have been experimentally investigated at about the same time, and independently, by Guthrie, Guyot, and Schellbach. In these papers numerous interesting experiments are detailed relative to the attraction and repulsion of various freely suspended substances, by tuning-forks and other vibrating bodies, and we may give the following quotations, as showing the striking and distinct character of the results obtained. We give, first, some quotations illustrative of the experimental results obtained by Mr. F. Guthrie.*

41. Experiment 7.—"To one end of a splinter of wood 0·5 metre long, a card 0·08 metre square was fastened in such a way that the plane of the card was vertical, and contained in the line

* 'Phil. Mag.,' Nov., 1870.

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of the splinter. The whole was hung from a fibre of unspun silk, and counterpoised. The tuning-fork was set in vibration, and was brought towards the card in three relative positions. In all three cases the card moved towards the fork. The rate at which the card moved was greatest when the fork was sounding loudest. In all three cases it was possible to draw the card from a distance of 0·05 metre at least."

To test the *reciprocity* of the motive tendency the following experiment was tried: Experiment 8.—"The tuning-fork was fastened to the end of a rod 1 metre long; the end of the rod was counterpoised, and the whole was hung from a silk tape." The description adds, that when a card was held near the vibrating suspended fork, the fork moved towards the card; this being evidently the exact converse of the previous experiment. The following quotation illustrates this point further: Experiment 9.—"Further, instead of a card, a second fork B was set in vibration and brought into the neighbourhood of the vibrating suspended fork A. In every case the suspended fork approached the stationary one." "Hence, to whatever cause the approach is due, the action is mutual." The following few quotations serve to show the distinct character of results obtained by M. Schellbach.* When a sounding box was used, the description adds, "The above-mentioned sounding box distinctly attracted and brought into contact with itself easily movable metallic sheets and balls, even such as weighed 120 grammes, and were at a distance of 8 centimetres." Another experiment was as follows: "A ball, weighing three kilogrammes, hanging from a silk thread 2 metres in length, could be set in visible vibration when the fork was stroked isochronously with the pendulum vibration."

The following account of an experiment is of interest, as pointing to the analogy between the vibrating tuning-fork put in resonance by waves of sound (air waves), and the vibrating molecule put in "resonance," so to speak, by waves of heat (ether waves): "These and the previously mentioned phenomena (i. e. phenomena of attraction) were also produced, although to a less degree, when a tuning-fork was set in vibration by means of a second fork in unison with it. Actions were still visible when the distance between the forks was one metre."

42. These striking experimental facts carry their practical deductions with them, and in their application to molecules vibrating in the ether, there are only two conditions, important in a mechanical point of view, which require to be satisfied, viz. first, the existence of an ether pressure of a value commensurate with the high static value of the effects observed in the case of vibrating molecules; and, secondly, the vibrations of molecules must take place with an energy commensurate with the energy of the effects. The first of these two conditions has been already con-

* 'Phil. Mag.,' June, 1871.

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sidered and disposed of; for it is not only possible to show that an adequate ether pressure commensurate with the effects is practicable, but the observed speed of a wave of light, as pointing to the high normal speed of the ether particles, renders the existence of a forcible pressure a necessity, although every allowance be made for the low density of the ether. The existence of this forcible pressure is evidently a necessary mechanical condition to the effects, for the pressure of the agent must, at least, reach the highest static value of the force with which the vibrating masses or molecules are urged together. Thus, in the case of the air, for example, the attraction of vibrating masses, such as for instance the mutual attraction of two vibrating tuning-forks, however great the vibrating energy, could never exceed or indeed reach the static value of 15 lb. per square inch of surface acted against, this being the limit of the normal air pressure, the approach of the forks being due to the excess of the normal air pressure above the reduced air pressure between the forks, due to the vibrations. In the case of the ether, therefore, where the observed effects in the case of vibrating molecules attain a static value far surpassing that possible in air, the existence of a forcible ether pressure is, therefore, an absolutely essential physical condition.

The second of the two physical conditions requiring to be satisfied, viz. the existence of a degree of vibrating energy in the case of molecules, commensurate with the observed energy of the phenomena of attraction and repulsion, we shall now proceed to consider more particularly.

43. *Absolute Mechanical Value of the Molecular Vibrations.*—In regard to the normal "temperature" (normal degree of molecular motion) possessed by the various materials on the earth's surface, one is perhaps liable to overlook, or at least not to appreciate fully, the fact that the absolute mechanical value of this molecular motion is extremely high. A general equilibrium of temperature tends to be maintained, and only changes of temperature (which are extremely small compared with the absolute temperature) can affect the senses, so that the absolute energy of the molecular vibrations (the absolute "temperature") might possess any value, however high, and yet the senses would be wholly unable to detect the fact of the existence of this energy, and only would the intensity of the molecular energy actually existing become apparent in the most striking manner if in any one instance this motion were to cease. From the fact, however, that a general equilibrium of molecular motion is maintained on all sides, its existence necessarily eludes notice, and there is therefore a tendency for the absolute mechanical value of these molecular motions and their practical teaching to escape a due appreciation.

44. In order to form a just estimate of the energy of the effects of attraction and repulsion capable of being produced by vibrating molecules, it is necessary to form an adequate realization of the

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absolute mechanical value of these vibrations, and the mechanical value of the vibrations of molecules must then be compared with the mechanical value of the vibrations of masses, such as the tuning-forks, &c., by which the observed effects of attraction, already described, were produced.

It may be safely assumed that the mechanical value of the vibrations of the tuning-forks, in the experiments referred to, was not greater than that which would be produced by a blow upon the prong, due to a fall of the fork through 10 to 20 feet, and thereby striking its prong against a hard surface. This is merely intended to give a rough idea of the small mechanical value of the vibrations of the forks (merely stroked with a violin bow) which produced the distinct effects of attraction described; the actual mechanical value of the vibrations being probably less than the above estimate.

We will now endeavour to investigate, approximately, the actual mechanical value of the vibrations of the small component parts of the fork, which are termed "molecules," to the vibrations of which (by the waves generated in the ether) the mutual "cohesion" of the molecules is to be referred. We will suppose the fork to be at the normal temperature of 60° Fahr., this representing an absolute temperature of 519 of Fahrenheit's degrees, reckoned from the absolute zero. The addition of 1° Fahr. to the temperature of a mass of water represents, as is known, an addition to the energy of the motion of its molecules, which would be competent to project the mass of water (i. e. each molecule) to a height of 772 feet, or is equivalent, in mechanical value, to the energy developed at the impact of the mass after a fall from the above height. The specific heat of iron or steel being one tenth that of water, the addition, therefore, of 1° Fahr. to the temperature of a mass of steel represents an addition of energy equal to that developed at the collision of the mass after a fall of 77·2 feet.

The actual value of the vibrating energy possessed by the molecules of the steel fork at normal temperature is, therefore, equal to the energy developed at the collision after a fall of the fork through $519 \times 77 \cdot 2$ feet, about $7\frac{1}{2}$ miles, this corresponding to a velocity of 1600 feet per second. If, therefore, we imagine the molecules of the fork to be without vibratory motion (i. e. without "heat," or at the "absolute zero") at the commencement of the fall through the above height, and that the work of the collision were entirely expended in developing vibratory motion in the molecules of the fork (raising the "temperature" of the fork), then the fork would be at 60° Fahr. after the collision. The vibratory motion of the molecules of the fork at normal temperature (60° Fahr.) therefore takes place with such an energy, that the vibratory motion if entirely utilized would be competent to project the molecules to a height of about seven miles, or to

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project the molecules of the fork apart at a speed in excess of that of a bullet.

45. If, therefore, the molecular vibrations take place with this intense energy, then surely the forcible effects of attraction observed in the case of molecules are only consistent with the high intensity of the vibrating energy possessed by them. If the feeble vibrations of a tuning-fork be competent to produce distinct effects of attraction, then if only due weight be given to the incomparably more intense vibrating energy of molecules which derive their energies from the powerful dynamic agency of the sun, then the power of the molecular attractions reconciles itself with ordinary mechanical principles, as powerful effects are the inevitable result of powerful causes. It may also be noted that the separating distances of the molecules of substances being extremely small, the energy of the wave motion set up in the ether is but little reduced by distance, also on account of the great subdivision characterizing the molecular state, the extent of surface exposed to the action of these waves must be exceedingly large.

46. These considerations have a general application, and the remarkable fact of the extreme variety of vibrating period observed in the case of molecules, the observation of which has formed a special study with the spectroscope, has a definite object, viz. that of fixing the "affinity," or special "combining power," of the molecule, for it is clear that if the movements of molecules comprised under the phenomena of "attraction and repulsion," be dependent on the molecular vibrations as a physical cause, then so important a change as a change of wave period, and indeed any change whatever affecting these vibrations, must have its influence on the effects of these vibrations, i. e. on the movements and deportment of molecules; an influence on the physical cause being necessarily attended by an influence on the physical effect, the vibrations supporting each other or interfering more or less as the wave period changes.

The vast variety of wave period observed points all the more convincingly to the fitness of the molecular vibrations as the regulator of the complex and varied effects exhibited in the movements of molecules in "chemical action," or those diverse molecular movements which belong to the science of chemistry, the remarkable diversity in the character of the physical cause producing naturally a remarkable diversity in the effects.

The terms "attraction" and "repulsion" serve as convenient terms to denote the direction of the motion or tendency to motion exhibited by masses or molecules due to a disturbance of the equilibrium of the dynamic action of the particles of the surrounding medium. The term "repulsion" gives some idea of the mode of action. Possibly a term less vague than "attraction" might be used with advantage: "attraction" and "repulsion"

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being simply *impulsion* in opposite directions of the mass or molecule under the dynamic action of the particles of the medium.

47. In viewing the phenomena of the movements and mutual actions of molecules as a physical problem, it really is not conceivable that anything could be more admirably adapted to produce the effects than the vibrations of the molecules, which also by variation of wave period are capable of building up the almost endless variety of chemical compounds. In fact, if the question be fairly examined into, there exists no other conceivable process by which one mass or molecule of matter could move or act upon another mass or molecule placed at a distance than by means of vibration. For in the first place, in order for a mass of matter to be capable of moving, or physically affecting a second mass placed at a distance without approaching it, the mass must have a motion of some kind so as to be capable of disturbing the surrounding medium, which forms the only physical connection between the masses. Secondly, since the mass or molecule in acting upon the second molecule maintains a fixed position, it follows that the motion of the molecule must take place in such a way that the molecule can maintain a fixed position, and nevertheless can disturb the surrounding medium. Now, a vibratory motion of the molecule constitutes the only conceivable means of satisfying these conditions, as by this form of motion the molecule can retain a fixed position by oscillating about a fixed point, and yet can disturb the surrounding medium by its motion. Hence, in a mechanical point of view, nothing can be more obvious or to the purpose than the vibratory motion of matter so constantly presenting itself in physical phenomena.

48. A molecule of matter surrounded by the ether cannot possibly be in motion without disturbing the ether, and thereby giving up or dissipating continually its motion in the surrounding ether. This disturbance of the ether by the motion of molecules is illustrated by the waves emitted by the molecules of substances, and the attendant loss or dissipation of the motion of the molecules is exemplified by the cooling (loss of molecular motion) of heated substances when suspended in the free ether. It follows, therefore, from this that the motion of molecules which is being continually dissipated in the ether must be sustained by some external source of motion, or otherwise the motion of molecules would soon cease. This is illustrated by the known fact that the motion of molecules is sustained by the sun, it being an important fact to observe that the character of the sustaining motion is a *vibratory* or wave motion traversing the ether.

The fact of the special character of the motion of molecules being a *vibratory* motion is therefore only an illustration of the simple mechanical principle that the motion of molecules must necessarily be that form of motion which admits of being sustained by the action of a *vibratory* motion traversing the surrounding ether.

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49. Thus the vibrations or "resonance" of masses by the sustaining action of air waves (such as waves of sound) and the vibrations, "resonance"—so to speak—of the smaller masses ("molecules") by the sustaining action of ether waves (the waves of heat) are in perfect analogy with each other: and in the same way a resonant mass and a "resonant" molecule (as proved by the spectroscope) is sustained by ("absorbs") a motion of the same character (same wave period) as it emits.

All physical effects being effects of motion, and since vibratory motion constitutes one of the fundamental forms of motion, it would be a thing to be expected beforehand that the general phenomena of vibratory motion, including the production of stationary vibrations in the intervening medium by the reflection of the waves from masses and molecules, would have a most important bearing on all branches of physical science, and have a most influential part to play in physical phenomena.

50. *The Static and Dynamic Effects of the Ether.*—It would appear *à priori* natural and even necessary that certain "static" effects, or effects of pressure, should exist in the case of that influential agent the ether, just as static effects of pressure are apparent in the case of the air. The phenomena of "cohesion" or the general phenomena of the aggregation of molecules, including the physical conditions governing the equilibrium of molecules, would come under the "static" effects of the ether; while the phenomena of the motions of molecules, such as the phenomena of chemical action, would come under the dynamic effects of the ether.

SECTION IV.

51. *Mode of the Production of Motion through Vibration.*—We shall now endeavour to investigate the mode or physical process by which motion is produced through vibration; and that not specially with the view to add proof to the circumstance that motion can be produced through vibration, this being already an observed fact in certain known experimental cases: just as, for example, we might investigate the mode or physical process by which a vibrating tuning-fork attracts a piece of card, without any view to add proof to the observed fact that the vibration of the fork can produce the attraction.

We have referred to the observed cooling of a heated substance in the free ether as a direct illustration of the fact that the motion of the molecules is being given up to the ether, and that, therefore, the emitted waves must on the whole contain an excess or surplus of energy, this surplus of energy representing precisely that lost

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by the molecules of the substance in the act of cooling down. We have now, therefore, to consider the mode or physical process by which the vibratory motion of a mass or molecule communicates *a certain excess or surplus of energy* to the surrounding medium.

As a simple and generally applicable example, we may take the case of a tuning-fork vibrating in air. Then considering any one of the emitted waves: the physical disturbance of the air, termed "a wave," is of such a nature that the component molecules of the one half of the portion of air forming the wave have received an increment of velocity, the component molecules of the other half of the portion of air forming the wave having suffered an equal decrement of velocity; also the amount of condensation in the one half of the wave is the equivalent of the amount of rarefaction in the other half. An air wave may therefore be properly regarded as a mass of air in which the uniformity of the distribution of the molecules and of their velocity has been disturbed in such a way that a transference of matter and of velocity has taken place from one half the mass of air to the other half.

52. But it may now be shown as an important point that although the increments of velocity equal the decrements, that nevertheless the special physical conditions under which these increments and decrements are experienced are such that a certain excess or surplus of motion is imparted to the air, or exists in the wave. This deduction follows from the consideration that the portion of air whose molecules receive an increment of velocity is condensed in the act of receiving it, owing to the advance of the vibrating mass (or prong) towards the portion of air which receives the increment of velocity; while, on the other hand, the portion of air whose molecules suffer a decrement of velocity is rarefied in the act of losing it, owing to the recession of the vibrating mass from this portion of air; so that, therefore, although the increments and decrements of velocity experienced by the molecules situated in the corresponding halves of the wave are equal, yet from the effect of the condensations and rarefactions, the number of air molecules which receive an increment of velocity is greater than the number which suffer an equal decrement, so that a certain excess of motion exists in the mass of air forming the wave, or the vibrating fork therefore imparts a certain surplus or excess of motion to the surrounding air. The quantity of air which thus in each wave receives an increment of motion for which there is no corresponding decrement, is represented by the difference in mass between the condensed and rarefied half of the wave. Since this difference in mass between the condensed and rarefied half of the wave, i.e. the condensations and rarefactions increase with the vibrating energy of the fork, and also the increments of velocity themselves increase; it follows, therefore, that the excess or surplus of energy imparted by a vibrating mass to the surrounding medium must increase in a rapid ratio with the vibrating energy. This con-

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sideration would have its special application in the case of molecules where the vibrating energy is known to attain a high intensity.

53. Secondly, it may be shown that an excess of energy is imparted to the surrounding medium by a vibrating mass or molecule, due to a second separate physical cause, which we shall now consider. We have observed that the speciality of a vibrating movement is to affect the normal velocity of the component particles of the medium in such a way that equal increments and decrements of velocity are experienced.

But it is an important principle to observe, that when masses of matter experience equal increments and decrements of velocity so that the mean velocity remains unaltered, that, nevertheless, the energy being as the square of the velocity, the value for the energy does not remain unaltered. Thus, if we take the case of two equal masses having equal velocities, which we may express by V, the energy in each case being expressed by V^2, and the total energy therefore by $2\,V^2$. If now we suppose one of the masses to receive an increment of velocity v, its velocity therefore becoming $V+v$, the other mass experiencing an equal decrement of velocity, its velocity becoming $V-v$; then although the mean value for velocity has remained unchanged, yet the value for energy has by no means remained unchanged, for the energy of each mass being as the square of its velocity, the total energy now becomes $(V + v)^2 + (V-v)^2 = 2\,V^2 + 2\,v^2$. Now the value for the total energy before this change of velocity took place was only $2\,V^2$. The total energy has therefore, by merely changing the velocities by equal amounts (so as not to affect the mean velocity), received a notable increase represented by the amount $2\,v^2$. This is an important point, on account of the direct and practical bearing which it has on the phenomena of vibratory motion; the above indicating that the change of the velocities of the component particles of the medium by equal amounts, which it is the special function of a vibratory motion of matter to effect, is itself a direct cause whereby a certain excess or surplus of energy is communicated to the medium.

54. Hence, taking this cause into account, together with the one previously considered, it may be observed that there exist two separate influential physical causes by whose action the vibrations of masses or molecules are in all cases attended by the communication of a *certain excess or surplus of energy* to the surrounding medium.

The deduction that by the vibrations of masses or molecules a surplus of energy is imparted to the surrounding medium, is clearly of direct and practical importance as regards the phenomena of "attraction," &c., for the communication of energy to the component particles of a medium implies necessarily, under certain conditions, an expansion or rarefaction of the medium, and

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a rarefaction of the medium is the very condition required for an "attraction."

The observed fact of the resistance offered by an aeriform medium to the passage of masses, or indeed the simple observation of the resistance encountered in waving a fan, constitute other illustrations of the fact that the vibrations of masses are attended by the communication of a surplus of energy to the surrounding medium.

55. Since the presence of other vibrating masses cannot possibly influence the amount of energy imparted by a vibrating mass to the surrounding medium, it follows that a substance at normal temperature is losing as much heat or is imparting as much energy to the surrounding ether as if the substance were completely isolated, or as if everything around were at the absolute zero of temperature, only the substance under normal conditions maintains its temperature unchanged, from the fact that the substance is receiving as much heat from surrounding objects as it expends. Taking normal temperature at 60° Fahr., then this represents an absolute temperature of 519 of Fahrenheit's degrees, reckoned from the absolute zero.

Since the waves developed in the ether by substances at normal temperature do not affect the senses, on account of the perfect state of equilibrium of motion which exists, or only an increase of temperature above the normal can affect the senses; in order, therefore, to be capable of forming a just idea of the amount of energy which is being given up to the ether continually by substances at normal temperature, it will only be necessary to suppose the temperature raised as much above the normal as the normal temperature is above the absolute zero, in which case substances would be giving up to the ether an addition of energy precisely equal to the energy which they were giving up at normal temperature. Accordingly, normal temperature being taken at 60° Fahr., we have therefore to add 519° to this temperature, giving 579° Fahr. A substance therefore at the burning temperature of 579° Fahr. has only received an addition of vibrating energy which is equal to that which it possessed at normal temperature, and which its molecules were actually imparting to the ether without affecting the senses. From this it may be judged what an amount of energy is being continually given up to the ether by the molecules of substances at normal temperature. If we take the case of water, which is a good radiator, and suppose a quantity representing one pound to be spread out into a layer or film, so that the vibratory motion of the molecules can be freely imparted to the ether, the area of the film being supposed such that the mass of water by radiation and absorption exchanges an amount of heat represented by only seven-tenths of a degree Fahr. per second, then it may be computed that the vibrating molecules of the pound of water at normal temperature are working up to about one-horse power in the amount of energy being continually given up to the

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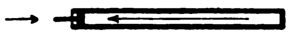
ether. These considerations have their direct application as regards the intensity of the static and dynamic effects capable of being produced by the vibrations of molecules.

56. In dealing with the question as to the mode in which motion is produced by vibration, we will suppose a special illustrative case as serving best to put the subject in its clearest light. Let us suppose a cylinder or tube (Fig. 2) containing air, a piston fitting into one end of the tube, the other end being closed. The piston placed just within the tube is supposed to admit of being put in rapid vibration, the limits of oscillation of the piston being supposed so small compared with the length of the tube that the influence of the change of volume of the enclosed air does not come into account. Then it follows necessarily from the previous considerations that a certain surplus of energy is imparted to the enclosed column of air by the vibrations of the piston. But since it is impossible to impart energy to the molecules of a mass of air without that mass tending to dilate, it follows that the confined column of air will, under the action of the vibrating piston, tend to expand and thus exert a pressure tending to drive away or repel the base of the cylinder and piston, and to expand the cylinder laterally, the energy of the effect being only limited by the energy with which the piston can be made to vibrate or oscillate. Since the surplus of motion imparted to the molecules of the air column accumulates at every stroke of the piston, it follows that the pressure would increase continually by simply continuing, even at a slow speed, the vibration of the piston, if it were not for the fact that an increase of the translatory motion of the air molecules is necessarily accompanied by an increase of the vibratory motion (heat) of the molecules, which form of motion can communicate itself to the molecules forming the cylinder, and thus be conducted away or dissipated, a limit being thus set to the rise of pressure which is thus made dependent on the energy of vibration of the piston. In the actual state of the case, therefore, the inference follows that the pressure will only rise until a stage is reached at which the amount of heat conducted away or dissipated through the cylinder is the precise mechanical equivalent of the work done in maintaining the oscillation of the piston, deducting therefrom the small unavoidable resistances due to the friction of the piston against the tube, &c.

Fig. 2.



57. If the sides of the cylinder were supposed to be partly formed of some elastic substance capable of distension, then the pressure exerted by the enclosed air would be necessarily followed by an expansion of the enclosing envelope, and this by a rarefaction of the enclosed air, the degree of rarefaction thus attainable being only limited by the degree of vibrating energy capable of being imparted to the piston. From these considerations

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we may deduce the important general conclusion that matter in stationary vibration tends forcibly to dilate and displace anything which hinders its free expansion.

58. We will now consider more closely the mode of vibration of the air column in such a case. It is evident that the air column would be thrown into stationary vibration by the reflection of the pulses of air from the base of the cylinder. We will first suppose, for simplicity, that the period of vibration communicated to the piston corresponds with the vibrating period of the air column, the air column in such a case vibrating as a whole in synchronism with the piston.

We then observe that the increments of velocity given to the air molecules are reflected from the base of the cylinder, back upon the piston, and in this case the time taken for a complete reflection is that of a single vibration, so that in this case an additional increment of velocity is given to the molecules of the air column at every stroke of the piston, which, if it were not dissipated in heat, would cause a continuous rise of pressure, and a continually increasing effort of the air to expand and rarefy itself.

59. A vibratory motion of matter would thus, in fact, appear to be one of the best possible mechanical means of communicating motion to the particles of a medium, and thereby causing the medium to expand forcibly and rarefy itself. In fact, when the physical conditions of the case are analyzed, we have the particles of the medium impinging continually with their normal velocity against a given mass of matter, so that it is only necessary to put this mass of matter in motion in order to communicate motion to these particles, and a vibratory motion is the form of motion specially adapted for this object, since by this form of motion the mass can communicate, continually, motion to the particles of the medium, and yet the mass can maintain a fixed position. Hence a vibratory motion of matter may be justly said to constitute the best-adapted mechanical means of accumulating motion in the particles of an aeriform medium, and thereby causing, under suitable conditions, a forcible rarefaction of the medium, this rarefaction of the medium being the physical condition required for an "attraction."

60. It may be further observed as an important point, as generally characteristic of the stationary vibration of a medium, that the motion of the oscillating air column, as in the present illustrative case, takes place in such a way that the condensed portion of the reflected wave meets the oscillating mass (piston) at its advance, while the rarefied portion of the wave meets the piston at its recession, so that for this special cause the increments of velocity are given at each impulse to a greater number of air molecules than would be the fact if the air column were not already in stationary vibration, so that for this special cause

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the work done by the vibrating piston upon the air column is augmented. The experiment of holding a vibrating tuning-fork over a resonance jar, when the fork loses its motion much more rapidly than under normal conditions, serves to illustrate the fact of the greater amount of work done by a vibrating mass upon the air when the air is in stationary vibration.

61. We will now, for further illustration, imagine the vibrating period of the piston to correspond with the vibrating period of the half column. Then the air column would, as is known under these conditions, break up into two oscillating halves or segments (Fig. 3), vibrating in synchronism with the piston, the two halves of the column rebounding from each other at the centre of the cylinder, and then rebounding simultaneously from the piston and the base of the cylinder. This case serves to illustrate well the expansive action attendant on the oscillations of the air column, the impacts of the halves of the column tending to drive out the ends of the cylinder; and since aeriform media propagate pressure equally in all directions, the sides of the cylinder must tend to bulge outwards, so that if the cylinder were partly composed of some elastic material it would expand laterally, this expansion being necessarily followed by a rarefaction of the enclosed air column, the degree of rarefaction thus attainable being only dependent on the vibrating energy of the piston. This illustrative case serves to convey a mechanical idea of the mode in which matter in stationary vibration tends to expand in every direction and displace that which confines it. If the character of the motion constituting a stationary vibration of matter be considered, as in the present case, it may be noted that each half of the air column simply performs a movement of oscillation between the centre and ends of the cylinder, so that each oscillating half of the column might be supposed replaced by an elastic sphere, which performs a reciprocating movement analogous to that of the half column, the two spheres rebounding from each other at the centre of the cylinder, and then rebounding simultaneously from the piston and base of the cylinder, the two spheres thus performing motions precisely analogous to those previously performed by the halves of the air column, the motion accumulating at each stroke of the piston, and the two spheres tending by their impacts to repel the ends of the cylinder in the same way as was the case with the oscillations of the two air masses.

Fig. 3.

62. If the piston were supposed to be made to oscillate to a more rapid period, then the air column would, as is known, divide into a greater number of oscillating parts or segments (Fig. 4), the principle involved in the motion being, however, precisely the same as in the case of two segments or in the case when the column oscillates as a whole. The segments into which an air column

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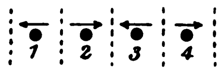
divides under the influence of vibration are well shown by the known experiment of putting a glass tube, having dust scattered in its interior, into stationary vibration by friction, when the enclosed air column being thus thrown into stationary vibration, the dust divides into a series of segments showing the corresponding division of the vibrating air column.

FIG. 4.

FIG. 5.



We may, therefore, again suppose the oscillating segments of the column (Fig. 4) to be replaced by elastic spheres (Fig. 5), each of which performs the reciprocating movement of the corresponding segment. Every alternate sphere, such as all those marked with the odd numbers, would at any given instant be moving simultaneously in one direction, while those marked with the even numbers move simultaneously in the reverse direction, this being the motion corresponding to the segments of the air column.

63. Now, it may be remarked as a point of interest that the character of this motion of the segments of the air column, or any column of a medium in stationary vibration, represents the character of the normal motion of the integral particles of the medium, when the resolved components of the motions of the integral particles of the medium in any two opposite directions are taken; precisely the same diagram having previously served in treating of the motion of the integral particles of an aeriform medium. It will be evident that this must be so, or the principle of the motion must be the same in both cases, since in both cases the character of the motion must be such that the column can be in equilibrium and maintain as a whole a fixed position in space, and, as before referred to, this is the only possible form of motion which satisfies these conditions, the motion in both cases taking place in such a way that as much matter at any given instant is moving in one direction as in the opposite. Thus it will be observed that the segments into which the column is divided move in such a way that the same quantity of matter is moving at any given instant in one direction as in the opposite, the sum of the segments moving in either direction representing half the column. A consideration of this analogy in the form of motion serves to show in a striking light the expansive action attendant on a stationary vibration of matter, or the motion of the oscillating masses of air into which the column is broken up tends to expand the column in all directions, or to dislocate and throw asunder its parts, just as the normal motion of the integral molecules of the column tends to expand it in all directions; indeed, the effect of throwing the air column into stationary vibration is simply to

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superadd to its own molecular motion a palpable mass motion of its parts. This tendency of matter when in stationary vibration to expand or dislocate its parts is well shown by the experiment of throwing a glass tube into forcible stationary vibration by friction, when the tube may be split into a series of rings, its vibrating parts flying asunder. Here the expansion is resisted by the cohesion of the glass. In the illustrative case of the vibrating column of air confined within the cylinder, the expansion of the column is resisted by the external envelope or cylinder, which consequently has to bear the pressure; and if means were given for the air column to expand freely, a rarefaction of the air would be the result, the degree of rarefaction attainable depending only on the energy with which the column is thrown into vibration.

64. The tendency of matter in stationary vibration to dilate and cause displacement might even be illustrated by the simple experiment of shaking longitudinally a corked tube partly filled with water and held horizontally, when the cork might thus be forced out by the oscillating mass of liquid. Here the stopped ends of the tube, when the tube is shaken longitudinally, play the part of two oscillating pistons throwing the enclosed liquid into vibration. It can be of no consequence, as far as the principle is concerned, whether the matter thrown into vibration be water, air, or the ether; only to produce a given effect, the speed of vibration must of course be greater as the matter concerned is less dense. In the above case the relatively very great density of the water enables a perceptible effect to be produced even by the slow shaking of the hand. A stationary vibration of matter is, in fact, simply a violent shaking of the matter acted upon, which therefore tends to expand in every direction, and drive away that which confines it; and if the matter in vibration be free to expand, then a forcible rarefaction is the result.

The above considerations all lead to the general conclusion that the method of vibration is a mechanical process eminently adapted to disturb forcibly the equilibrium of pressure of a medium, which may be attended by forcible movements of masses of matter, whose positions of equilibrium are determined by the equilibrium of pressure of the medium about them.

65. In the application of the above deductions to masses vibrating freely in a medium, such as to the case of vibrating molecules and free vibrating masses generally, we have only to consider the state of the case when the envelope is wanting, such as the case when the enclosing cylinder, or the distensible envelope in the illustrative example is removed; when the piston would be oscillating freely opposite the base of the cylinder, in perfect analogy with the prong of a vibrating tuning-fork oscillating freely opposite a piece of card, or with two molecules vibrating in opposition to each other.

It will be evident that the effect of removing the lateral

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envelope will be to afford facility for the lateral expansion, and therefore rarefaction, of the intercepted air column, or the column of the medium intercepted between two opposed vibrating masses (or molecules), the absence of the envelope enabling the oscillating column of the medium to expand laterally with freedom, the column thereby becoming rarefied.

Thus, if we take the case of a vibrating tuning-fork held in proximity to a lightly suspended piece of card, then the increments of velocity imparted to the molecules of the column of air intercepted between the vibrating prong and the card, accumulate by repeated reflections between the opposing surfaces of the prong and the card, producing a rarefaction of the air column, whereby the excess of pressure of the air at normal density at the back of the card coming into action, drives the card towards the prong. If the fork be supposed to be maintained at a constant degree of vibrating energy, then the increments of energy which, under the action of the two physical causes before dealt with, are continually imparted to the molecules of the intercepted air column, and which accumulate by repeated reflections from the card and prong, would be necessarily followed by a continually increased rarefaction of the intercepted air column, were it not for the fact that a portion of the vibrating energy of the column is dissipated laterally into the surrounding medium, by which a fixed limit is put to the rarefaction of the air column, the degree of rarefaction being thus made dependent on the vibrating energy of the prong. The same considerations apply in the case of two molecules vibrating in opposition to each other, as in the case of any vibrating masses whatever, or masses of matter which emit waves.

66. The above deductions may be stated in one general conclusion, viz. that the vibrations of masses or molecules of matter are in all cases necessarily attended by a rarefaction or displacement of the intervening medium: this conclusion holding, however distant the masses may be from each other, or however feeble the vibrations; the intensity of the effect becoming greater by an increased proximity of the masses, or by an increase of their vibrating energy.

SECTION V.

67. *The Physical Conditions of the Equilibrium of Molecules.*— In proceeding to consider the physical conditions governing the equilibrium of molecules, it may be stated, first, that the equilibrium of a molecule of matter depends on the equilibrium of pressure of the medium about it.

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We have observed that a vibratory movement of matter, under such conditions that the waves are reflected and thereby stationary vibrations are formed in the medium, is well qualified to disturb the equilibrium of pressure of the medium. If we suppose the imaginary case of a vibrating molecule of matter completely isolated, then stationary vibrations could not be formed in the medium, the equilibrium of pressure of the medium about the molecule could not be disturbed, and the molecule would be in equilibrium. But if we suppose a second molecule placed in proximity, then the medium about the molecule is specially disturbed at that side where the second molecule is situated, due to the formation of stationary vibrations in the medium intervening between the molecules by mutual reflection of the waves, a rarefaction of the intercepted vibrating column of the medium which abuts against the opposed molecules being the result. The condition of equilibrium of the molecules will therefore depend upon the fact whether the pressure of the intervening vibrating ether column is greater than, equal to, or less than the ether pressure at the remote sides of the molecules, where the normal ether pressure exists; the molecules being driven in the one direction or in the opposite, or remaining in equilibrium, according to the relation of these two pressures.

Now, the rarefaction which attends the stationary vibration of the intervening ether column would, by reducing the ether density, i. e. by reducing the number of ether particles which impinge against the sides of the molecules which oppose each other (i. e. the side of each molecule where the vibrating column terminates), tend to cause a mutual approach of the molecules under the action of the superior number of ether particles which impinge against the remote sides of the two molecules where the ether density possesses its normal value, this physical effect corresponding to an "attraction."

On the other hand, the direct action of the pulsations of the vibrating ether column, or the direct action of the increments of energy given to the particles of the column, would, considered by itself alone, tend to propel the molecules farther apart, a physical effect corresponding to a "repulsion."

These are, therefore, the two opposing physical influences which determine the position of equilibrium of each molecule, each molecule being driven in the one direction or in the other, or remaining in equilibrium, according as the direct influence of the pulsations of the intercepted ether column or the indirect influence of the rarefaction attendant on these pulsations attains the upper hand, or the two opposing influences become equal.

68. It follows, therefore, that two molecules can only be in equilibrium under those special physical conditions when by a special adjustment of distance and vibrating energy these two opposing physical influences happen precisely to counteract each other; the

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molecules being urged in the one direction, or in the opposite, "attracted," or "repelled," according to which influence predominates under the existing physical conditions.

69. When the separating distance of two molecules is made to vary, this change of distance is necessarily accompanied by an important change in the physical conditions about the molecules. Firstly, a variation of distance is attended by a change in the relative proportions of the intercepted vibrating ether column, whose length is determined by the intervening distance, and upon the physical state of which the conditions of equilibrium of the molecules intimately depend. Secondly, a variation of distance is attended by a change in the energy of the stationary vibration of the intercepted ether column. When the molecules are placed in very close proximity, the intercepted ether column becomes short relatively to its breadth, the lateral area afforded for expansion becomes contracted, and the pulsations of the column are more concentrated against the opposing molecules, tending to separate them; also the energy of the stationary vibration of the column has been increased, owing to the increased proximity of the molecules. It would appear reasonable to conclude from this that the physical influence producing a "repulsion" would predominate in the nearest proximity to a molecule—an inference which accords with observed facts.

On the other hand, when the separating distance of two molecules is increased, the intercepted ether column becomes long relatively to its breadth, more lateral area is afforded for expansion, which would conduce to a rarefaction of the column, a result favourable to an "attraction." Also, the energy of the direct action of the pulsations of the column has been reduced by the increase of distance. To take an illustrative case: The aggregation of vibrating molecules, known as the "solid," comport themselves in such a way that when the distance of the molecules is reduced, they "repel," and when the distance is increased the molecules "attract," or a solid resists an attempt both to compress and to dilate it, each molecule taking up a position or point of stable equilibrium, the situation of which point varies by a change of vibrating energy (change of "temperature"). In order for the general phenomena of alternating "attraction" and "repulsion" exhibited in the case of molecules to be produced, it is only necessary that the two opposing physical influences which determine the equilibrium of the molecules should not preserve the same constant ratio to each other under the varying physical conditions attendant on a change of distance. Thus the diminution of the ascendant influence up to equality and beyond, by an increase of distance, would produce alternating attraction and repulsion, separated by a neutral point of equilibrium.

70. We will now notice a few of the facts as they actually exist. Although there are some exceptions in the case where the

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vibrating periods of the molecules differ, there is a broad or general agreement in certain of the effects observable, more particularly in the case where the vibrating periods of the molecules are the same. The aggregation of molecules in the solid state in the vast variety of materials forms an instance where the vibrating period of the aggregated molecules is the same. Now, in the general case of molecules of similar vibrating periods, and also in certain other instances, the first marked effect observable on approaching the molecules towards each other, is a repulsion; then by a further approach there is an attraction, and in the closest proximity there is again a repulsion. Thus, in the general case of solid bodies, two separate portions of the same substance will not readily unite even when pressed together, or the molecules in the first instance repel. It is practicable in certain cases to apply a sufficient pressure to overcome this first repulsion, and to bring the molecules into proper proximity for the attraction to come into play. Thus, two freshly cut surfaces of lead may be made to unite by pressure, this being also the case with glass and some other substances. After this degree of approach has been attained, i. e. after the molecules have taken up those positions of stable equilibrium which constitute the aggregation of the molecules in the solid state, then a pressure is necessary in order to cause a further approach, and the molecules recoil or recede into their previous positions of stable equilibrium when this pressure is removed; so that therefore the attraction changes into a repulsion in the nearest proximity to the molecules.

71. Since, therefore, the repulsion experienced on the first approach of two molecules changes into an attraction by a further approach of the molecules, it follows that a certain point must exist at a certain definite distance outside a molecule (the vibrating energy being supposed kept constant), at which point, if a second similar molecule be placed, it is in equilibrium; but if the molecule be placed a short distance outside this point, it is repelled; and if it be placed a short distance inside this point, it is attracted. Accordingly, since the shifting of the molecule to a short distance to either side of this point causes it to be driven farther away from the point, this point might, therefore, be termed "the neutral point of unstable equilibrium," where repulsion changes into attraction.

Further, since after this neutral point has been passed and the attraction coming into play, the molecules are urged a short distance towards each other, each molecule then takes up a position of stable equilibrium, where attraction changes (inversely) into repulsion; it follows that a second neutral point must exist outside a molecule (in nearer proximity to the molecule than the first neutral point), at which point, if a second similar molecule be placed, it is in stable equilibrium. Since also when the molecule is shifted to a short distance to either side of this second neutral

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point, it returns to it again when left to itself, or when the disturbance ceases; this second neutral point in nearest proximity to the molecule might, therefore, be termed "the neutral point of stable equilibrium."

72. As an illustration of this deportment of molecules when, instead of separate portions of a solid, separate or discrete molecules are concerned, we may take the case of a vapour or gas. As a generally applicable example, we may take the case of iodine. This substance exists as a vapour at the same temperature at which it exists as a solid, as is in general the case with solids more or less. The discrete molecules of iodine, therefore, which compose the vapour, although at a temperature (vibrating energy) suited to the formation of the solid state, yet these molecules can rebound from each other in the free translatory motion of the gaseous state without uniting. The discrete or separate molecules, therefore, as was to be expected, deport themselves towards each other as two separate portions (i.e. parts composed of a number of molecules) of the solid substance, or the discrete molecules forming a vapour or gas comport themselves towards each other, as the outer layer of the molecules of a portion of the solid substance would comport themselves to the outer layer of the molecules of another separate portion of the same substance, i.e. the molecules in the first instance repel.

As an example of a similar fact in a case where the vibrating periods differ, we might instance the case of oxygen and hydrogen gases, a mixture of which in a proportion suited to an explosion may be kept for any length of time without the molecules uniting; and although the molecules are interchanging motion among themselves in free translatory motion, they do not under normal conditions come into sufficient proximity to unite. In order to effect this, some disturbing cause is necessary, such as, for example, the application of incandescent matter (matter in intense molecular vibration), or perhaps a sudden forcible concussion.

73. *The Reciprocity of Attraction and Repulsion.*—It is a noteworthy fact that a complete reciprocity exists in the phenomena of attraction and repulsion, or, in other words, each of the two masses or molecules concerned is acted on with precisely equal energy. This has been experimentally proved, in the series of experiments before noticed, to be a characteristic of the effects produced by vibrating masses generally.

In one case specially described, a vibrating tuning-fork was suspended in such a way as to be free to move, and on a piece of card being held near the fork, the latter moved towards the card, precisely as (conversely) the freely suspended card would have moved towards the fixed vibrating fork. The description adds: "Hence, to whatever cause the approach is due, the action is mutual."

Now, it may be shown that this mutual action is one of the

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necessary consequences of the fact of the existence of *stationary* vibrations in the medium between the influencing masses, as in this special case, in the column of air intercepted between the vibrating prong and card; the same considerations applying to vibrating molecules as to any vibrating masses whatever.

The physical characteristic of a stationary vibration being a mutual or reciprocal reflection of the pulsations of the intervening column of the medium from the surfaces of the opposed masses, reciprocity of action is therefore a necessity, the energy of the movement of either mass depending solely on the relation that the pressure of the intervening column of the medium in stationary vibration bears to the normal pressure of the medium; as in the present case, the energy of the movement (approach) of either the fork or the card depends on the relation that the pressure of the intercepted rarefied column of air bears to the normal air pressure, and this pressure of the vibrating air column intercepted between the prong and card must be mutual or equal for each surface, since the pulsations of the column are mutually reflected. The intercepted vibrating air column abuts against the opposing surfaces of the prong and card, the pressure being propagated between the surfaces by mutual reflection, so that a perfectly mutual or reciprocal action becomes a necessity; indeed, the one pressure owes its existence to the opposite reacting pressure.

In the same way in the case of molecules, reciprocity of action is the necessary consequence of the mutual reflection of the emitted waves; the common movement of two vibrating molecules towards or from each other (attraction or repulsion) depending solely on the fact whether the pressure of the intercepted ether column in stationary vibration is greater or less than the normal ether pressure.

74. From the above considerations, therefore, the general conclusion follows that one of the necessary results of a *stationary* vibration of the medium is to make the effects perfectly reciprocal or mutual.

It may further be shown that the effects are not explicable by the vibrations of the masses themselves alone, but that the *stationary* vibration of the intervening medium is the sole physical cause concerned in the phenomena of attraction and repulsion, and the mere emission of waves without the action of the *stationary vibration of the medium* would be incompetent to produce the effects.

This may be proved from the following considerations. Firstly, the production of waves is not in itself attended on the whole by a rarefaction or absolute displacement of the medium, the condensation in the one half of the wave being the equivalent of the rarefaction in the other half, and it is only when the waves become stationary by mutual reflection, and the energy thus accumulates at a fixed spot, that a permanent rarefaction of the medium can

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be produced. Now, since a rarefaction of the medium constitutes the only possible physical means by which an attraction (approach) can be produced by vibration, and, further, since a rarefaction is only possible under the condition of a stationary vibration of the medium, it therefore follows that a stationary vibration of the medium can be the sole physical cause concerned in producing an attraction.

75. When justly viewed, the observed experimental fact previously referred to, where a fixed card attracts or causes the approach of a freely suspended vibrating tuning-fork, affords in itself a complete illustration of the truth of this principle. In this case the card does not vibrate at all, and yet the card acts upon the fork with the same force that the vibrating fork acts upon the card. This equality of action, therefore, proves at once that the vibrations of the fork give it no special advantage, or the waves emitted by the fork have of themselves no special influence independent of the stationary vibration of the intervening air column; for if this were the case, the effect would be one-sided and not mutual. The very fact that the mass which does not vibrate at all can produce as great an attraction as the mass which vibrates, itself proves that that which is concerned in the effect must be something independent of the vibrations of the mass itself, and, moreover, something placed under such physical conditions as to make the effect mutual. This is only true of the intercepted column of the medium in stationary vibration, whose pressure (whatever its value) must affect both opposing masses equally, the effect being solely dependent on the stationary vibration of the intervening medium, the effect produced by a mass being (by a given energy of vibration of the intercepted column of the medium) independent of the fact whether the mass vibrates or not; or by a given energy of the stationary vibration of the intercepted column of the medium, the effect is the same whether one or both masses vibrate, or they vibrate with different degrees of energy. This point is further illustrated by the observed perfect reciprocity of action in the case of aggregated molecules, whose vibrating periods and vibrating intensities differ (chemically combined molecules). The *stationary vibrations produced in the intervening medium* by the mutual reflection of the emitted waves, therefore, constitute the sole physical cause concerned in the effects comprised under the phenomena of "attraction and repulsion," and the action of the stationary vibrations is also the sole means by which the reciprocity of the effects admits of being explained.

76. The only conceivable way in which a vibrating suspended tuning-fork could be affected by the presence of a distant card, is that the medium about the fork is in some way affected by the presence of the card. Now, since the card does not itself vibrate, the only possible way that it can affect the medium about the

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fork is by reflecting the impinging waves back upon the fork, by which stationary vibrations are produced in the intervening medium, and to these stationary vibrations alone, therefore, can the approach of the fork possibly be referred. Further, since in the converse case when the fork is fixed and the card movable, the card is acted on with precisely equal force, it follows, therefore, that the same physical cause, i. e. the stationary vibrations of the medium, must be solely concerned in this case also, i. e. in both cases, whether it be the approach of the vibrating fork or the approach of the card.

It may be further observed in the illustrative case of the vibrating freely suspended fork and fixed card, that unless the reflection by the card of the emitted waves, back upon the fork (and the consequent production of stationary vibrations in the intervening medium), be taken into account, by which means the medium about the fork at that special side of the fork where the card is situated is specially affected, it would be a complete impossibility to explain why the presence of a card should cause a vibrating suspended fork to commence moving towards it; for unless these stationary vibrations were produced, the medium about the fork would be in precisely the same physical state when the card is present as when the card is absent, and consequently there would be no more reason for the suspended fork to commence moving in a particular direction (to be "attracted") when the card is present than there would be when the card is absent, the same reasoning applying in the case of molecules as in the case of any masses of matter whatever.

77. The above considerations all lead to the general conclusion that the stationary vibrations produced in the intervening medium are the sole physical cause concerned in the phenomena of attraction and repulsion, and that the mere emission of waves, independent of the stationary vibrations, would be incompetent to produce the effects.

78. There is one point, perhaps, worthy of notice in regard to the establishment of reciprocity of action, viz. that this must require a certain time to establish itself, excepting in that special case when both masses commence to vibrate at the same instant and with the same energy. Thus, if we suppose the case where one mass is put in vibration after another mass has been placed in the vicinity, then in such a case the inference is necessary that the action would be without reciprocity for a short period, or one mass would be acted on alone for a short period. Thus, if we take the illustrative example of a tuning-fork and card, and suppose that the card is first brought into the vicinity of the fork, and then that the fork is put into vibration; then it is necessary to conclude that the card would be influenced a certain fraction of time before the fork; for the vibrations of the medium become stationary at the card at the instant when the wave reflected

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from the card meets the emitted wave, i. e. at the instant when the reflected wave commences its return, whereas the vibrations of the medium cannot become stationary at the fork until the reflected wave has completed its return, i. e. has traversed the entire interval between the card and fork, and has reached the fork. Until the vibrations of the medium become stationary at the fork, or until the emitted wave reflected from the card has reached the fork, the fork cannot possibly be influenced by the presence of the card, for before the reflected wave reaches the fork the medium about the fork continues to remain in precisely the same physical state as if the card were not present. Hence, in such a case, the inference is necessary that the one mass is affected before the other, although after the completion of the stationary vibration of the medium reciprocity becomes perfect, the time required for reciprocity to establish itself being represented by the time required for the wave to traverse the intervening distance separating the masses. These considerations possibly might have a more important application in a case where the separating distance of the influencing masses was great.

SECTION VI.

79. *Mode of the Development and Absorption of Heat in Expansion and Contraction.*—It is a known fact that by the compression or contraction of matter heat is generated, and by the expansion of matter heat is absorbed; but the mode or physical process by which this result is attained, or the cause why a mere movement of translation of the molecules of a substance in a particular direction should cause the molecules to vibrate with increased energy, and a movement of translation in the opposite direction should cause the molecules to vibrate with reduced energy, requires explanation.

This may be shown to be another of the necessary consequences resulting from the fact of the existence of stationary vibrations in the medium between opposed vibrating masses and molecules. The character of a stationary vibration consisting simply in an oscillation of the intervening column of the medium, either as a whole or in parts, the extremities of the column abutting against and rebounding from the two opposed vibrating masses or molecules; it follows, therefore, that an approach of the two masses or molecules in which act each is driven against the oscillating column, must cause the column to rebound with greater energy, just as an elastic sphere will rebound with greater energy when the surface from which it rebounds

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is driven against it. Hence it follows, necessarily from this, that the act of approach of the opposed masses, such as the approach of two vibrating molecules, will be necessarily attended by an increase in the energy of the stationary vibration (oscillation) of the intervening ether column. It is, however, important to observe that the period of vibration (oscillation) of the column coincides precisely with the period of vibration of the molecules, since the column is itself put in vibration by the molecules. Hence the increase in the energy of vibration of the ether column, due to the movement of approach of the molecules, must be necessarily attended by an increase in the energy of vibration of the molecules themselves, which vibrate in synchronism with the column, and against which the oscillating column abuts, just as, conversely, any artificial increase of the vibrating energy of the molecules would affect the column. Thus it follows that a movement of translation of two molecules towards each other, as takes place by the compression of matter, will necessarily be attended by an increase in the vibrating energy of the molecules (development of heat); precisely analogous but converse considerations applying in the case of the recession of the molecules (expansion).

80. The interchange of motion between two gaseous molecules in the normal state of a gas would afford an illustration of both processes, the vibrating energy of the molecules being increased at their approach, and reduced at their recession; or the two molecules in their interchange of motion are alternately heated and chilled. If we regard the state of the case at the point when the rebound of the two vibrating molecules commences, then the intercepted pulsating ether column which does the work of urging the molecules apart, loses an amount of energy equivalent to the work done; or, in other words, the pulsations of the column are reduced by an amount represented by the translatory motion imparted to the molecules. This loss of vibrating energy by the column necessarily reacts upon the molecules, i. e. the vibrating energy of the column is, in the readjustment of the equilibrium of motion, partly made good at the expense of the vibrating energy of the molecules, the receding molecules thereby losing a certain portion of their vibrating energy, or the molecules are chilled.

The loss of vibratory motion ("absorption of heat") which accompanies expansion is beautifully illustrated by the known experiment by which carbonic acid is produced in the solid form by the free evaporation of the acid in the liquid form. In this case, when the vapour is allowed to escape freely, the vibrating molecules are driven apart with such velocity that the energy of vibration of the ether column intercepted between any pair of receding molecules is so reduced by the work it performs, and consequently the vibrating energy of the molecules themselves is reduced to such a degree that the molecules become fitted to take up the solid state.

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81. The converse case of the augmentation of vibrating energy ("development of heat") in the approach of molecules (contraction) is well illustrated by the simple apparatus known as the "fire syringe," by which a piece of tinder is ignited by the sudden compression of the air by a forcible blow struck upon a piston. In this case the velocity with which the air molecules are driven together is such as to augment their vibrating energy almost up to that of flame.

82. It may be observed, that however great the energy with which the molecules are urged together, and consequently however forcibly the intercepted ether column may be acted upon, this need not necessarily disturb the synchronism of the oscillation of the column, for the column can adapt itself to a more energetic movement by oscillating through a greater amplitude, without necessarily changing its oscillating period, and therefore without detracting from the power which its synchronism gives it of reacting upon the molecules.

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SECTION VII.

83. *The Dynamic Effects of the Ether.*—We will now turn to the consideration of the dynamic effects of the ether, and we may take the well-known case of the formation of water, by the combination of the mixed gases oxygen and hydrogen, as this case serves as a type of chemical processes, and, indeed, serves as an illustration of the process involved at the interchange of motion between the ether and the molecules of matter generally; the variety in the effects consisting in differences in the energy of action in the case of molecules of different vibrating periods, the variety in the effects depending also on the greater or less number of molecules which are in the act of combination at the same time. Thus the slow rusting of an iron wire, and the burning of a similar wire in oxygen gas with the scintillation of sparks, serve to represent two cases where the differences merely depend on the differences in the number of molecules which are in the act of combination at the same time, *each* separate molecule in the rusting of the wire entering into combination with the same velocity or intensity as each separate molecule of the wire when burnt, only in the former case the number of molecules in the act of combination at once is not sufficient to disturb the ether enough for the waves to be capable of affecting the eye.

84. If we regard a mixture of the gases oxygen and hydrogen, then before the match is applied the vibrating molecules are in free translatory motion, exchanging motion among themselves; any pair of molecules at their approach throwing the ether into forcible stationary vibration, and not coming into sufficient

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proximity to unite. In order for the molecules to combine, they must, by the action of some force, be driven together beyond the outer neutral point of unstable equilibrium, which, as before set forth, separates the combined from the gaseous state. Although the force required to effect this is small compared with the energy with which the molecules are urged together after the neutral point is passed, it is nevertheless sufficient to prevent the spontaneous combination of the molecules. When, however, any means whatever, capable of forcibly disturbing the molecules, is resorted to, such as the application of a substance in intense molecular vibration, as, for example, an incandescent solid, a flame, &c., or even perhaps a sudden forcible concussion, indeed anything which suffices to drive a few of the molecules into proper proximity; when this is effected, the rarefaction produced in the intervening ether column thrown into forcible oscillation by any two approximated molecules, comes into effect, and the normal ether pressure on the remote halves of the pair of molecules being thereby brought into action, the molecules are driven forcibly together, they approach the internal neutral point of stable equilibrium, and are carried beyond it by their momentum, but rebound again, the molecules oscillating about this point as a position of stable equilibrium.

Each pair of molecules during combination being driven at a high speed against the oscillating ether column intercepted between the approaching molecules, the oscillations of the column are thereby greatly intensified, and, therefore, those of the molecules which vibrate in synchronism with column, this giving rise to the ether waves of heat and light observed at the combination of the gases. At the same time the high intensification of the vibrating energy after combination has, by the stationary vibrations suddenly set up in the intervening ether, the effect of driving apart in all directions the molecules of water vapour, a general translatory motion (the motion characteristic of gaseous matter) being thus set up, the whole vaporous mass tending forcibly to expand in all directions, and producing the effect known as the "explosion." It is of course clear that the combination of a few molecules, in the first instance, by the application of a flame, has the effect, by the molecular disturbance thus set up, of causing the practically instantaneous combination of the entire gaseous mass.

During the process of combination, the ether particles by whose action the molecules are driven towards each other, lose thereby a certain portion of their normal velocity; the amount of motion lost by the ether during the process being precisely that transferred to the molecules. This loss of motion sustained by the ether next the molecules commences to be replenished from the very commencement of the movement of the molecules, the ether particles simply continuing to exchange velocities (their normal mode of motion), and thus the spherical wave representing

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the loss of motion is automatically carried off at the velocity of the particles themselves, or with the speed of a wave of light, so that the ether particles next the molecules are prepared for a fresh effort even before the gaseous molecules have had time fully to approach each other. If it were not for this high normal velocity of the ether particles, a sustained effort of a high intensity would be impossible to the ether, for only on this condition could fresh motion be drawn with adequate speed from the stores of motion contained in the ether at a distance. Moreover, only on this condition could the loss of motion sustained by the ether be, during the short time of the explosion, subdivided or distributed over a vast radial volume of the ether, whereby the local disturbance of the equilibrium of the ether is reduced to a minimum. The spherical wave representing the loss of motion sustained is carried off with extreme rapidity, and soon, from the vast number of ether particles encountered which increases as the square of the distance, the loss of motion becomes so subdivided that, although existing as a whole, it soon practically ceases to exist as regards each particle taken separately.

85. From the known mechanical value of the process of combination of the gases oxygen and hydrogen, it may be computed that if the entire energy given up by the ether were expended solely in developing the translatory motion of approach of the molecules in the process of combination, the maximum velocity imparted to the hydrogen molecule would amount to about nine miles per second; but since it is necessary to conclude that the translatory motion of approach of the molecule from the instant of its generation commences to be converted into vibratory motion (heat), it would follow that the full value of the translatory motion cannot be attained, although the inference appears warranted that a considerable part of the full value is attained; for, firstly, since the intensity of the vibratory motion (heat) depends on the velocity with which the molecule is urged against the oscillating ether column, the observed intensity of the heat therefore indicates that a high velocity of translation must have been attained by the molecule; and secondly, the inference is necessary that the most intense development of vibratory motion (heat) takes place on the shortening of the ether column at the approach of the molecules, the vibrations of the column (due to the rapid forward and backward reflection of the pulses attendant on its reduced length) being then intensified most forcibly; and, therefore, by reaction the vibrations of the molecules, the molecule then also having acquired its greatest velocity, and having reached the inner neutral point where the work of the ether ends, the molecule being driven by its momentum against the oscillating ether column from which it finally rebounds, and coming to the end of its path by converting its translatory motion into vibratory motion (heat). From these considerations, therefore, it would follow that the

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greatest development of heat takes place, not during the development of the translatory motion, but afterwards, the translatory motion being first developed in great part, and then converted into heat, so that from this the inference would be warranted that the full mechanical value for the translatory motion is nearly attained.

The combination of the mixed gases oxygen and hydrogen being one of the most intense examples of chemical action known, and the mass of the hydrogen molecule being exceptionally small, it would follow that the velocity of the hydrogen molecule in this case must constitute one of the highest instances of molecular velocity developed in chemical action. However, even if the full value of the velocity (nine miles per second) were attained, this velocity constitutes but a small fraction of the normal velocity of the ether particles (that of a wave of light), so that it becomes apparent that the ether is an agent mechanically well adapted to follow up and to effect with ease the rapid movements of the molecules of matter even in the most intense instances of chemical action, as in the case of explosives, rapid combustion, &c.; or, in other words, the ether is, from the high normal velocity of its particles, an agent physically adapted to effect those extremely rapid changes in the positions of equilibrium of molecules, exhibited in the general phenomena of chemical action.

If, on the other hand, the ether particles did not possess a high normal velocity, or if by the same amount of enclosed energy the mass of the particles were greater and the speed less, then the production of the same velocity of motion in the molecules of matter could not take place without the loss of a considerable percentage of their absolute velocity by the ether particles, which would be attended by a palpable rarefaction or disturbance of the equilibrium of pressure of the ether; for it is important to observe that not only can a given decrement of velocity be sustained by the particles with a less disturbance, as the absolute velocity of the particles is greater, but also the disturbance is less from a second cause when the absolute velocity of the particles is greater; for the speed with which the wave representing the loss of motion is carried off, and consequently the volume of the ether over which the loss of motion is subdivided, depends on the absolute normal velocity of the particles, the disturbance being less in proportion as the number of particles over which the loss of motion is subdivided is greater. Hence a high normal velocity of the particles of the agent contributes from two separate causes to reduce the disturbance of the equilibrium of the agent attendant on the production of a given dynamic effect. The existence of a high normal velocity for the ether particles is therefore the essential mechanical condition to render the ether adapted as a motive agent in an intense and long-continued development of motion, as exhibited in the intense molecular motion of rapid combustion, &c. On account of the

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high absolute normal velocity of the ether particles, the proportionate loss of velocity sustained by the particles even in the most intense instances of chemical action, such as the explosion of gunpowder, for example, is not sufficient to produce a palpable disturbance of the equilibrium of the ether, and the loss of motion is rendered imperceptible by rapid distribution over a vast volume of the ether.

SECTION VIII.

86. *Correlation of the Effects of Air Waves and Ether Waves.*—The mutual approach of two molecules vibrating in the ether may be compared to the mutual approach of two (freely suspended) tuning-forks vibrating in air, or to the approach of a freely suspended piece of card or plate of any substance towards a tuning-fork vibrating in air.

The motion of the card or plate towards the vibrating fork being due to the excess of the normal air pressure at the back of the plate, over the reduced air pressure in front, due to the rarefaction produced by the stationary vibration of the air column intercepted between the vibrating prong and the plate; then when the motion of the plate towards the fork commences, the air molecules which rebound from the remote surface of the plate lose a portion of their velocity by transference to the plate. This loss of velocity is rapidly restored by the neighbouring air molecules in the interchange of motion continually taking place between the molecules, and thus the loss of motion is carried off into the surrounding air in the form of a wave, and at a speed somewhat less than the normal speed (sixteen hundred feet per second) of the air molecules, or with the speed of a wave of sound.

87. Though the effect must be extremely feeble here, it is theoretically deducible that the energy of vibration of the fork must, during the approach of the plate (in analogy with the development of vibrating energy (heat) at the approach of molecules), be slightly augmented, due to the intervening vibrating air column being driven against the prong with which it vibrates in synchronism. The effect here must of necessity be extremely feeble, neither the rate of approach nor the energy of vibration in this case being at all comparable with the case of molecules; also the effect would be probably more than masked by the dissipation of the vibrating energy of the fork into the surrounding air during the approach, for the vibration of the fork, unlike that of the molecule, is not continuously maintained by external sources. However, a physical cause must have its effect whether it be feeble or not.

It is, therefore, important to observe that the work done at the

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approach of the plate cannot be directly due to the vibrations of the fork, for if the movement of translation of the plate were derived from the vibrating energy of the fork, then the approach of the plate would have the effect of reducing the vibrating energy of the fork by an amount equivalent to the work done, whereas the approach of the plate has the exact contrary effect. The motion imparted to the plate must, therefore, be entirely derived from the surrounding air, whose molecules lose an amount of motion or energy equivalent to the translatory motion imparted to the plate, including the small extra amount of vibratory motion imparted to the fork during the approach of the plate.

The vibrations of the fork have the indirect object of maintaining the rarefaction of the air in front of the plate, or they serve the purpose of putting the air into a suitable physical condition such that an interchange of motion can take place between the molecules of air and the plate, the air molecules alone, and not the vibrating fork, being the source of energy in the approach of the plate, the same considerations evidently applying in the case of the mutual approach of two (freely suspended) vibrating forks.

88. So in the case of the approach of two molecules vibrating in the ether, the energy concerned in effecting the approach (combination) of the molecules can be solely derived from the surrounding ether, and not from the vibrations of the molecules themselves. This is illustrated by the observed effects; for if the energy concerned in the approach of the molecules were derived or abstracted from the molecular vibrations, then the vibrating energy (heat) of the molecules would be necessarily reduced at their approach by an amount equivalent to the work done, whereas the exact contrary is the fact. The entire energy developed at the approach of the molecules, including both the translatory motion developed and the vibratory motion (heat) developed, must be therefore solely derived from the surrounding ether, which loses an amount of motion equivalent to the motion developed: the vibrations of the molecules merely serving the indirect purpose of putting the ether into a suitable physical condition, such that an interchange of motion can effect itself between its particles and the molecules; the ether, and not the molecular vibrations, being the source or motive agent of the molecular motion observed.

In the case of the combustion of a piece of coal, for example, the molecular motion developed is solely derived from the surrounding ether, and not from the molecular vibrations of the coal, the energy of these molecular vibrations (the heat) being greatly intensified in the process of combustion. The motion developed in the coal and molecules of air in the process of combustion is therefore solely derived from the motive agency of the surrounding ether: the normal molecular vibration of the coal (sustained by the dynamic action of the sun) merely serving the indirect purpose

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of putting the coal in a fit state, such that an interchange of motion can effect itself between its molecules and the ether, or a mass of coal is simply a piece of mechanism for utilizing the motion of the ether.

89. The above considerations serve to indicate that in addition to the well-known striking analogy which exists between the effects of ether waves and those of air waves, as exhibited in the phenomena of light and sound, a still further analogy exists as regards the effects due to a disturbance of the equilibrium of pressure of the medium by the action of the waves, as exhibited in the movements ("attractions," &c.) of masses vibrating in air, and of molecules vibrating in the ether; the intensity of the effects in this latter case being greater in proportion as the intense ether pressure renders possible effects of a higher static value, and in proportion as the energy of the vibrations of molecules sustained by the powerful agency of the sun, incomparably surpasses the feeble vibrations mechanically produced in masses.

SECTION IX.

90. We have referred to the decrement, or loss of motion, sustained by the ether particles in developing motion in the molecules of matter (in chemical action, &c.) as a "wave." Now, since the term "wave" in general applies to regular or periodic increments and decrements of velocity experienced by the component particles of an aeriform medium, the periodic character of such waves enabling them to accumulate motion, so as to be capable in certain cases of affecting the senses (as in the phenomena of light and sound); it is well, therefore, to distinguish the true character of the wave representing the loss of motion sustained by the ether in the production of any movement or dynamic effect. Although it is necessary to conclude that in the performance of work by the ether, as in the case of combustion, for example, a separate wave, representing the equivalent loss of motion sustained by the ether, must be produced at the approach (combination) of each separate pair of molecules; still this could not be regarded as a "wave" in the ordinary sense, since this form of wave represents only a decrement of motion, and not an equal increment and decrement, of which a "wave" consists in the general meaning of the term. Moreover, these decrements of motion sustained by the ether as the motive agent in the movement of approach of the molecules, do not in any way follow in regular or periodic succession as in the case of "waves" commonly so termed, and by which they are enabled to affect the senses, but

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these waves or decrements of motion are superimposed upon each other, and the distinctive character of each wave (i.e. the wave attendant on the approach of each separate pair of molecules) is lost, or the waves are necessarily merged into each other, which would tend to produce simply an appreciably uniform loss of motion in the ether around, spread over a vast concentric volume of the ether, the loss of motion being proportionally very small as regards each ether particle taken separately, the loss diminishing uniformly as the square of the distance from the origin. If we regard an isolated wave, or the decrement of motion developed in the ether at the combination of a single pair of molecules, then this wave being due to the translatory movement of approach of the entire mass of the molecule, would be of disproportionately greater length than the rapid and periodic waves of heat simultaneously generated due to the vibrations of the molecule during its approach, these short waves of heat being, therefore, superimposed upon the wave representing the decrement of motion: the short waves (waves of heat and light) being also capable, from their periodic character, of appealing to the senses.

So in a somewhat analogous manner the wave or decrement of motion developed in the air, at the mutual approach of two vibrating suspended tuning-forks, and which represents the loss of motion sustained by the molecules of air in urging the forks together, must be of much greater length than the periodic waves due to the rapid vibrations of the forks during their approach, these short waves being superimposed upon the wave representing the decrement of motion. The disproportionately greater length of the wave representing the decrement of motion will become apparent when it is considered that if the approach of the forks lasted but one second, the loss of motion would in that time be spread over a spherical mass of air of more than a thousand feet radius, or the loss of motion is so subdivided as to be totally incapable of appealing to the senses in any way, while, on the other hand, the periodic character of the waves due to the vibrations of the forks (the waves of sound) enables these waves to affect the senses.

SECTION X.

91. *The Static Effects of the Ether.*—We will return here to the consideration of the static effects of the ether as exhibited in the phenomena of "cohesion," chemical union, &c., i.e. the general phenomena of the aggregation of molecules.

As an illustrative example having a general application, we may take the case of a metallic bar submitted to a tensile strain.

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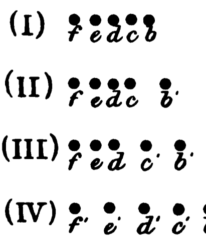
Though in reality it is impossible to apply a tensile strain to matter, since matter consists of discrete or wholly unconnected parts (molecules and particles) separated by empty space, and it is impossible to direct a strain across empty space, or to put space under strain, still the term "tensile strain," in contradistinction to "compressive strain," may be convenient in practice to denote the particular direction in which it is desired to produce motion.

92. If b, c, d, &c., Fig. 6 (I.), represent any line of molecules in the direction of the length of a metallic bar, these molecules being in equilibrium with the ether pressure, and at a certain distance apart, which remains constant so long as the vibrating energy ("temperature") of the bar is kept constant. Then when the bar is said to be under a "tensile strain," the direction of the movement of the molecules is from each other, or the ends of the bar are moved to a greater distance apart. We will consider, therefore, any single molecule b, and suppose it to be moved to a greater distance from the next molecule c, taking up the new position b' (II.), it being supposed that the farther end of the bar is fixed. Then the equilibrium of the ether pressure is disturbed by this movement of the vibrating molecule into a new position, the energy of the stationary vibration of the ether column intercepted between b and c being reduced by the increase of the distance of the two molecules, the effect being that the pressure exerted by the vibrating column upon the opposing halves of the molecules b' and c is reduced, the pressure of the column being necessarily reciprocal, or equal for each molecule, owing to the mutual reflection of the pulsations. The ether pressure upon the opposite sides of the molecule c is therefore no longer equal, the lengths of the two oscillating ether columns at opposite sides of the molecule being unequal, the molecule is therefore driven into a new position c' (III.), or the molecule is moved by the ether pressure, until by its increased distance from the next molecule d, the ether pressure upon the opposite sides of the molecule c' becomes again equal, the same considerations applying to all the molecules of the bar. The effect of moving the end molecules of the bar outwards (as in the case of a "tensile strain") has, therefore, the result of causing all the vibrating molecules of the bar to recede to uniformly increased distances (IV.), this uniform distance of the vibrating molecules being the physical condition required for uniformity in the ether pressure, by which the positions of equilibrium of the molecules are regulated. During the time the strain lasts, therefore, the value of the ether pressure between the opposed vibrating molecules of the bar (i. e. where the molecular distances are abnormally increased) is less than the

FIG. 6.



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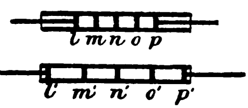
normal ether pressure existing outside the bar, by an amount which represents the static value of the strain.

The mode of action in the case of a tensile strain, in some respects at least, although the analogy is evidently not strict, admits of rough illustration, if we suppose a glass tube, Fig. 7 (1), containing a series of sliding discs, *l*, *m*, *n*, *o*, *p*, fitting air-tight in the tube, the spaces between the discs being supposed occupied by air at ordinary atmospheric density, the discs being thus in equilibrium, or the air pressure, i. e. the energy of the impacts of the air molecules upon the opposite sides of each disc is the same. If, then, the two extreme discs be moved outwards, as occurs in the case of a tensile strain, the remaining discs will all take up new positions of equilibrium *l'*, *m'*, *n'*, *o'*, *p'* (2), such that the intervening distances become again equal to each other, this being the condition required to satisfy the equality in the air pressure upon the opposite sides of the discs, the whole system being uniformly distended, and returning to its previous position of equilibrium when the strain ceases.

Fig. 7.

(1) 

(2)

93. There would be, perhaps, a natural tendency to assume that because the density of the ether is so extremely low, the distance of its particles must be proportionately great, and that, therefore, this agent would not be physically adapted to control steadily and forcibly the molecules of matter in positions of stable equilibrium, such as to control the molecules of a steel bar, for example. It is, therefore, well to keep practically in view the fact that although this agent has a very low density, yet its component particles may be in extremely close proximity, or the agent may be extremely compact and well adapted to exert a perfectly uniform pressure about a molecule, for there is no limit to the degree of close proximity into which the particles of the medium may be brought by the simple means of an extreme state of subdivision of the matter forming the medium. Since this extreme state of subdivision is undoubtedly the fact in the case of the ether, it is well, therefore, in dealing with the phenomena of "cohesion" or the static effects of the ether generally, to realize clearly and practically the ether as an extremely close and compact body, although possessing an extremely low density. In other words, although the density, i. e. the volume of matter relatively to the volume of space, is small in the case of the ether, still there is nothing to prevent the particles from being in extremely close proximity to each other, under the simple condition of an extreme state of subdivision, the agent thus becoming very close and compact, and mechanically well adapted to control forcibly the molecules of matter in positions of stable equilibrium.

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SECTION XI.

94. *Maximum Values of Cohesion, &c.*—The phenomena of "cohesion," "chemical union," &c., or the general phenomena of the aggregation of molecules being dependent on the molecular vibrations as a physical cause, it would therefore be reasonable to conclude that variation of vibrating energy (variation of "temperature") would have a most marked influence on these phenomena; as is found to be the fact. Further, since when a physical cause ceases to exist, the effect also ceases; it follows that at the absolute zero of temperature (absence of vibrating energy) the general phenomena of "cohesion," including the aggregation of molecules in "chemical union," would cease to exist. Also, since an increase of vibrating energy(elevation of "temperature") above a certain degree has the effect of separating all molecules from each other, as illustrated by the effect termed "evaporation" in the case of molecules of similar vibrating periods, and the effect termed "dissociation," in the case of molecules of dissimilar vibrating periods (molecules aggregated in chemical union), it follows, therefore, that a maximum value must exist for "cohesion," or in the case of the aggregation of molecules generally; or for every substance a certain degree of vibrating energy (temperature) must exist, which is most favourable to the stable aggregation of the molecules; an elevation of temperature above this point, or a fall of temperature below this point, being both followed by a weakening of the cohesion of the molecules of the substance.

Since the aggregation of similar molecules to form masses (usually distinctively termed "cohesion") has a less stability than the more intimate grouping of dissimilar molecules about a common centre in definite numbers (definite proportions) to form clusters or compound molecules (chemical union), it would be reasonable to conclude that signs of a weakening of the molecular action, by lowering the temperature, would first present themselves in the case of "cohesion," though it is quite possible that the comparatively feeble means of reducing temperature at our command (when compared with the absolute temperature) might not be sufficient to give marked signs of a weakening of the molecular action. We are not aware that experiments with the best possible means for lowering the temperature have been made with this special object, nevertheless there may be certain effects which have presented themselves, and which would tend to illustrate this point. Thus it is a well-known and prevalent opinion, grounded on observation, that metals, such as iron, become brittle or more liable to fracture at low temperatures, which would indicate a weakening of the molecular action; indeed, it is perhaps scarcely a questionable point that an extreme reduction of temperature does conduce to render substances brittle or more friable,

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which would tend to the same conclusion. However, since all substances on the earth's surface have a high absolute temperature, it would not perhaps be reasonable to expect marked effects to present themselves under the circumstances of the case. If, on the other hand, we turn to the case of cosmical matter in space, which may recede to vast distances from the sun, then the conclusion is necessary that the effect in question must occur. Although the absolute zero of temperature cannot be said to exist anywhere, since the stellar radiations must have their effect in all parts of the ether of the visible universe, still in the case of masses removed to vast distances from the sun, where the wave movement set up in the ether by the sun's action might be practically said to have ceased to exist, then the conclusion is necessary that the almost total loss of vibrating energy by the molecules of the mass by continual dissipation in the ether, must have its effect on the energy of the molecular action dependent on vibrating energy, resulting in almost total loss of cohesion by the mass. It is quite possible, however, that such effects under these conditions might escape our notice. However, there may be certain observed facts which would point to this, and which may perhaps be worth noticing in connection with this subject. Taking the case of those cosmical masses known as meteors: these bodies are of relatively small mass, and are known in some cases to recede to vast distances from the sun, the orbits of some of them having been determined, and, as a significant fact, identified in certain cases with those of comets. If there were an actual physical connection between these bodies and comets, it would appear as if an actual change or disintegration of the matter of these bodies were going on. The small mass of these meteoric bodies, and the great distances to which some of them recede from the sun, would be precisely the two physical conditions most favourable to produce the effect in question. What may be the origin of the meteoric dust known to exist? We do not mean to put forward that there is actually conclusive physical indication of the disintegration of matter at a low temperature, but what evidence there is would seem to favour the conclusion, which is at all events a necessary one on theoretic grounds.

The possibility of the separation of the molecules of matter effecting itself at a low temperature would appear to have an important bearing on the question as to the perpetuity of physical phenomena, or the continuance of physical change in the universe; for the separation of molecules would be the one condition necessary to render possible the eventual combination of the molecules under the action of the ether with the evolution of heat and light, or this would be the physical condition required for physical processes to recur or to repeat themselves, as consistent with the continuance of physical change and activity in the universe.

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SECTION XII.

95. *Mechanical Value of the Action of the Ether on Molecules.*—We may here cite a few facts and figures illustrative of the great energy of the molecular phenomena, the contemplation of which in connection with a definite physical cause may have some interest; the great energy and intense pressure of the ether being well illustrated by these phenomena.

We will take the well-known substance, water. It is a known fact that the energy developed at the combination of 8 lb. of oxygen with 1 lb. of hydrogen is mechanically equivalent to 47,000,000 foot-lb. From this it may be deduced that by the explosion of the mixed gases, the intensity of the energy developed would be adequate to project the mass of liquid thus formed to a height of eight hundred and forty miles in opposition to gravity.

The ether pressure which urges vibrating molecules together being, on account of the action of the stationary vibration of the intervening medium, necessarily perfectly reciprocal or equal for each molecule, and the mass of the oxygen molecule being eight times that of the double hydrogen molecule constituting the water molecule; also since the velocity developed is inversely as the mass, it follows therefore that in the mutual approach of the molecules during the process of combination, the double hydrogen molecule will receive from the ether eight times the velocity imparted to the oxygen molecule. Hence it may be deduced that the intensity of the energy imparted to the hydrogen molecule during the process is such that it would be competent to project the molecule to a height of about six thousand seven hundred miles, this corresponding to a velocity of about nine miles per second imparted to the molecule. These are simply physical facts following from the known mechanical value of the process of combination of the gases.

96. Now, if we knew the exact distance traversed by the hydrogen molecule in its approach towards the oxygen molecule, within which distance the above velocity (nine miles per second) was acquired, it would then be possible to determine the actual value of the portion of the ether pressure which was active in urging the molecules together, compared with the value of gravity; for the distance required to be traversed under the action of gravity in order to acquire the above velocity is known (viz. six thousand seven hundred miles), and the static value of the physical agency which produces a given velocity in a mass of matter is inversely as the distance traversed by the mass in acquiring this velocity.

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The fact before referred to, that a certain part of the translatory motion developed in the molecule during the short distance traversed by it in the process of combination is converted into vibratory motion, will not affect the comparison, the total energy in the form of motion being the same in any case.

Although the actual distance traversed by the hydrogen molecule in acquiring an energy represented by a speed of nine miles per second is not known, still we may fix a limiting value for this distance, or a value which is with certainty greater than or outside the actual fact, and from this may be deduced the lowest limiting value for the intensity of the ether pressure which was concerned in the effect. It may be taken as quite certain that the distance is less than a millionth of an inch, as this distance is quite accessible to an ordinary microscope, and indeed cannot be regarded as a molecular dimension at all. It will be observed, therefore, that by as much as this distance, taken as a basis, is greater than the actual distance, by so much will the result arrived at for the intensity of the ether pressure concerned in the effect be less than the reality, or be under-estimated.

In order, therefore, to compare the value of the ether pressure active during the process of combination of the molecules with the value of gravity, we must take the distance which would require to be traversed by the molecule under the action of gravity, in order to acquire the same velocity (nine miles per second) as was acquired in the distance traversed by the molecule in the process of combination, and we must divide the one distance by the other. Therefore, dividing 6700 miles by $\frac{1}{1000000}$ inch, we obtain the quotient 424 billions, in round numbers.

This result shows, therefore, that with the above limiting value for the distance traversed by the molecule, the value of the ether pressure which acts against the hydrogen molecule and urges it towards the oxygen molecule is 424 billion times greater than the weight of the double hydrogen molecule, or the value of gravity acting upon it. It may, as before stated, be taken as certain that this estimate for the intensity of the ether pressure is less than the actual fact, since the distance traversed by the molecule has undoubtedly been taken too large. Moreover, this result only represents the difference of the ether pressure upon the opposite sides of the molecule, effective in the process of combination, and not the value of the normal or total ether pressure itself. However, the result arrived at is sufficient to indicate the high value of the ether pressure and the high intensity of the store of motion enclosed in the ether, as the motive agent in these forcible molecular movements of matter.

97. Since the work done in separating molecules is appreciably equal to the work done in the combination of the molecules, it would be possible, therefore, from the above data, to form an estimate of the direct tensile strain or pull that would be required,

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in order to separate from each other the oxygen and hydrogen molecules forming a given quantity of water, it being imagined that a strain could be applied for this object. Thus, if we take a grain of water, then the value of the strain required to separate the molecules being four hundred and twenty-four billion times the weight of the hydrogen molecules, and the total weight of the hydrogen molecules in a grain of water being one ninth of a grain; we have accordingly 424 billions $\times \frac{1}{9}$ grain $= 3{,}000{,}000$ tons, in round numbers. This result shows, therefore, that under the condition that a movement of the hydrogen molecule through a distance not greater than one millionth of an inch would effect separation, a direct tensile strain amounting in total value to not less than three million tons would be required to separate the components of the compound molecules forming one grain of water, or this represents the absolute value of the portion (or difference) of the ether pressure active in opposing the separation of the molecules.

As before remarked, a millionth of an inch being unquestionably too large as an estimate for distance traversed, the result arrived at for the absolute value of the strain will be by so much less than the actual fact. Also the above result gives only the mean value of the strain, and not its maximum value. The result may, however, serve as a further illustration of the high intensity of the pressure of the ether, by which this agent is mechanically qualified to control thus forcibly the equilibrium of the molecules of matter.

98. *Important Influence of Subdivision.*—One of the most important practical consequences following from the extensive state of subdivision, which is the characteristic of the molecular condition of matter, is the vast extent of surface which is thereby brought under the action of the ether pressure. This is a fact of importance, by a due appreciation of which the great energy of the action of the ether upon molecules will appear no longer discordant or inconsistent, but the fact may be brought into harmony with ordinary mechanical principles, this vast extent of surface being the fitting mechanical condition for the production of static and dynamic effects of extreme intensity.

If, for the purpose of illustration, we suppose a sphere one inch in diameter to be subdivided into a number of small spheres, each one ten millionth of an inch in diameter, then the surface thus exposed would amount to about 5 acres, the total surface increasing directly in proportion as the diameter of the spheres is reduced. Even the air pressure upon such a surface might be reckoned by thousands of tons. What must, therefore, be the case with the intense ether pressure acting upon the molecules of matter? The extremely high figures previously arrived at as a limiting estimate for the direct static strain that would be required to separate the constituent gaseous molecules forming one grain of water (as representing a portion of the ether pressure upon these molecules)

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will no longer appear discordant when due consideration has been given to the vast extent of surface exposed by these molecules to the play of the ether pressure.

Some idea may perhaps be formed of this, if it be considered that in order to bring this surface into view it would be necessary for the quantity of water forming one grain to be spread out into an extensive film or layer only one water molecule in thickness; it being realized that to separate the components of the compound molecules the ether pressure over the entire film would have to be acted against.

When the high intensity of the ether pressure, and the vast extent of surface exposed to this pressure, are conjointly taken into account, then the observed power with which molecules are controlled in stable equilibrium, and the observed extreme energy of the movements of molecules when the equilibrium of pressure is disturbed, as exhibited in the general phenomena of chemical action, combustion, &c., reconcile themselves with the ordinary principles of mechanics.

SECTION XIII.

99. *The Impalpable Nature of the Ether.*—An intimate connection may be shown to exist between the normal speed of the particles of an aeriform medium and the disturbance produced by the passage of masses of matter through the medium.

By the movement of translation of a mass through an aeriform medium the resistance encountered depends (as previously treated of in connection with the vibrations of masses and molecules) on the amount of condensation of the medium produced in front and of rarefication produced in the rear of the moving mass, since this is one of the conditions upon which the amount of energy imparted to the medium by the passage of the mass depends; the resistance encountered being simply the measure of the energy imparted to the medium. If there were no condensation and no rarefaction of the medium produced by the passage of the mass, then the number of impinging particles which receive motion in front of the moving mass would be equal to the number of impinging particles in the rear, which transfer an equal amount of motion to the mass; but on account of the existence of the condensation and rarefaction the number of particles which receive motion in front is greater than the number which lose motion in the rear, the excess in the number of particles which receive an increment of velocity for which there is no corresponding decrement being represented by the difference between the condensation and the rarefaction,

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this difference increasing with the velocity of translation of the mass.

Further, by the passage of a mass through an aeriform medium, there is a second physical condition by which energy is imparted to the medium. Although by the passage of the mass the impinging particles of the medium in front and rear experience equal increments and decrements of velocity, the mean value of the velocity therefore remaining unchanged; yet this, as previously referred to, is necessarily attended on the whole by an increase in the sum total of the energy of the particles; so that this forms the second physical cause of the resistance encountered by the passage of a mass through an aeriform medium, and this would constitute a cause for a certain resistance, even if there were no condensation whatever of the medium formed in front of the moving mass.

It is of course clear that if the density of the medium were extremely small, the resistance offered under the action of both these causes might be extremely small.

100. It is now an important point to observe that the amount of condensation of the medium formed in front, and the amount of rarefaction in the rear, of the moving mass will depend on the normal speed of the component particles of the medium, for the speed with which the condensed wave is carried forward and dissipated depends directly on the speed with which an interchange of motion can take place between the particles, i. e. on the normal speed of the particles.

The actual rate of transmission of the wave, though dependent on and proportional to the normal speed of the particles, will necessarily be to a certain extent slower than the normal speed of the particles, from the fact of the interchange of motion between the particles taking place also obliquely to the line transmission of the wave. In the case of the air, for example, the speed of whose component molecules may be taken at 1600 feet per second, the condensed wave of displacement due to the passage of a mass would be carried forward at a somewhat less speed than this, or at the velocity of a wave of sound. In the case of the air, therefore, on account of the very moderate speed of its molecules, the resistance encountered and disturbance produced by the passage of masses, even at moderate speed, are considerable. The speed of a cannon shot is even as great, and perhaps sometimes even greater, than the velocity of forward transmission of the condensed air wave in front of the shot, hence the great resistance offered by the air to projectiles, the air molecules in the rear having barely sufficient velocity to follow up the projectile. It is evident, therefore, that even if the air had as low a density as the ether, it would, on account of the slow normal speed of its molecules, be completely unfitted to afford passage to masses at planetary rates, or its equilibrium would be totally upset.

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In the case of the ether, on the other hand, the wave of displacement is carried forward at the speed of a wave of light, so that speeds of hundreds of miles per second are actually attained by cosmical masses, without disturbing the equilibrium of the ether, the wave being carried forward and dissipated so rapidly that there is no time for an appreciable condensation to accumulate in front of the moving mass. The motion of the ether particles is so rapid that equilibrium is almost immediately re-adjusted on the slightest disturbance, and there is not time for any disturbing effect to accumulate. The high normal speed of the particles of the ether is therefore one of the essential physical conditions to adapt this agent to afford free passage to cosmical masses (the planets, &c.) at high speeds, without disturbance of its equilibrium.

101. Hence the general conclusion may be drawn that the higher the normal speed of the particles of an aeriform medium, the less is the equilibrium of the medium disturbed by the passage of masses through it, or the more impalpable does the medium become. The higher, therefore, the normal speed of the particles of an aeriform medium, the more does the presence of the medium elude detection, or the more impalpable the medium becomes, and the less probability is there for its existence to be detected by endeavouring, as it were, to probe it with masses, i. e. to disturb its equilibrium by moving masses of matter through it. This deduction has its direct application in the case of the ether, the known impalpable nature of which is another physical indication of the high normal speed of the particles of this agent.

102. *The Physical Qualities essential to a powerful Dynamic Agent.*—It might be considered at the first thought, that because the ether is so impalpable and its density is so low it would not be an agent suited to produce forcible mechanical effects, or it might be inferred, on the first consideration of the subject, that the thin impalpable ether would not be suited to act forcibly upon the masses and molecules of matter and produce powerful dynamic effects, such as those exhibited in the case of explosives, &c. Now this, like many other first impressions, will become totally altered after a due consideration of the subject.

There is, unquestionably, a natural tendency to associate ideas of energy with large visible masses of matter in motion. This is not to be wondered at, since these forms of energy appeal directly to the senses, whereas the movements of molecules or particles of matter do not. If, therefore, misleading inferences are to be avoided, it is well that this natural tendency should be guarded against; for the motions of molecules and particles of matter might well possess an intensity of energy far surpassing that of any motions of visible masses; indeed, energy in this form might almost attain any value however high, and yet would necessarily be wholly incapable of appealing directly to the senses.

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There is a certain tendency, for example, to ignore, or at least not adequately to realize, the high intensity of the concealed molecular motion which is termed "heat." Thus, for instance, the energy of a passing shot is fully realized, and yet it may be shown that the energy of the molecular motion ("heat") possessed by the shot at normal temperature, and while at rest, represents about double the energy of the translatory motion of the shot at the instant of discharge.

The normal rate of motion (1600 feet per second) of the molecules of air is almost explosive in its energy; yet from the fact that these moving molecules are too small to affect the senses directly, there is a natural tendency to overlook the existence of this energy. The space occupied by the air molecules being very small compared with the space unoccupied; if therefore we were to imagine the component molecules of a cubic foot of air suddenly to lose their motion, a practical vacuum would be formed, and the sudden restoration of equilibrium would produce a dynamic effect resembling an explosion. The stoppage of the motion of the component particles of a cubic foot of ether would be followed by a dynamic effect, the high intensity of which could only be realized by an adequate appreciation of the energy enclosed by this agent.

103. In turning to the consideration of the physical qualities essential to a powerful dynamic agent, we may first observe that the existence of a high velocity in the particles of the agent in their normal state is an indispensable condition, for unless this be the fact, an intense development of motion or an intense dynamic effect could not be produced by the agent; in fact, unless the particles of the agent had a high velocity, they would be incapable even of following up the motions of the masses in which they develop motion. Again, this high normal velocity of the particles is the sole condition on which the motion expended by the agent in the production of a forcible dynamic effect can be replenished with speed, and the loss of motion be subdivided or spread over an extensive volume of the agent, or over a large number of the particles of the agent in a short space of time.

Secondly, minuteness in the moving particles being the necessary condition to render a high speed practicable to the particles, it follows, therefore, that minuteness in the particles, or an extremely subdivided state of the matter forming the agent, is a second essential condition to a powerful dynamic agent.

It is important to note that this condition is necessarily followed by an absolute concealment of the existence of the motion from the senses, so that for an intense store of motion or energy to exist, the concealment of its existence is a necessary condition.

Thirdly, a low density in the agent or the existence of but a small quantity of matter in the unit volume of space may be shown to be an essential condition to a powerful dynamic agent.

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This will be clear when it is considered that if space were encumbered with a quantity of matter, i.e. if the agent were dense, the agent would itself obstruct the very motions it develops, or, in other words, a high velocity could not be imparted without the motion of the moving masses being greatly interfered with and obstructed by the agent; so that, in fact, for the attainment of energy, the agent must rely upon speed rather than upon mass; it being also a noteworthy fact that the energy rises as the *square* of the speed.

Moreover, it is an important mechanical point to observe that by the absence of mass the energy becomes more concentrated, or by a reliance upon speed rather than upon mass, a greater quantity of energy admits of being concentrated upon a given spot; whereas the attainment of the same absolute amount of energy by means of large masses and slow speeds would render it impossible for the energy to be concentrated upon a small area (such as against a molecule of matter, for example), which concentration of energy is absolutely essential for the production of intense dynamic effects.

104. The above considerations, therefore, lead to the general deduction that to constitute a powerful dynamic agent the essential physical conditions are, firstly, a high normal speed for the component particles of the agent; secondly, that the particles should be minute, or that the matter forming the agent should be in an extremely subdivided state; and thirdly, that the quantity of matter relatively to the unit volume of space should be small, or that the agent should possess a low density.

This deduction has its direct practical application in the case of the ether, where we find precisely these physical qualities developed to an extreme degree.

105. That the use of minute masses endued with a high velocity is the proper mechanical proceeding when an intense dynamic effect is required, is illustrated in practice in many ways. Thus, when for any engineering purpose a powerful mechanical effect is required, then recourse is had to gunpowder. The effect observed at the explosion of gunpowder is simply produced by the action of small masses of matter ("molecules") endued with a high speed. If, therefore, gunpowder, by means of the motion transferred to its molecules by the ether, represent in the act of explosion the true ideal of a powerful dynamic agent, how much more must this be the case with the ether itself?

106. Since, therefore, we observe that a high velocity of the component particles and a low density are the qualities essential to a powerful dynamic agent, and since this high velocity of the component particles is precisely the quality which necessarily renders the agent impalpable, it follows, therefore, that the known impalpable nature and low density of the ether, instead of indicating that this agent is unfitted to produce powerful

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dynamic effects, should, when justly viewed, lead directly to the opposite conclusion.

107. To illustrate somewhat further the connection which exists between the speed of the component particles of an aeriform medium and its impalpability, we may imagine the case of a confined mass of air cooled down to such a degree that the translatory motion of the air molecules has almost ceased. Then, in such a case, the air would become quite palpable, or by a mere motion of a mass of matter through it, the air might be completely displaced, vacua formed in parts, and the density increased in other parts; indeed, the molecules of air, if almost without translatory motion, might be collected in groups. The air would, in fact, by the almost complete loss of the normal speed of its molecules, have lost its elasticity and the power of eluding the grasp, which the translatory motion of its molecules at normal temperature enables it to do.

It is important, therefore, to observe that the more palpable the mass of air becomes, the less is the store of energy enclosed, or the less would the air be qualified to produce a dynamic effect; and to apply, therefore, this principle generally, the fact of a medium being palpable would indicate that it was totally unfitted as a dynamic agent, and conversely the fact of a medium being impalpable, by which the existence of the medium eludes direct detection by the senses, would, by pointing clearly to the high normal speed of the particles of the medium, directly indicate that the medium was well qualified as a dynamic agent.

108. If we imagine conversely the confined mass of air to be heated, so as to increase the translatory motion of its molecules, then the air would become more and more impalpable, it would elude the grasp, and it would be more difficult to disturb its equilibrium by moving masses of matter through it, and therefore the presence of the air would be more difficult to detect by this means. At the same time it is well to note that the more impalpable the mass of air becomes (due to the increase of speed of its molecules), the more intense is the store of energy enclosed, and the greater is the pressure exerted, and the more fitted does the air become as a dynamic agent.

These considerations have their direct application in the case of the ether, the remarkable impalpability of which could not be better illustrated than by the fact that no ordinary rate of motion of masses of matter has been found capable of affecting the transmission of the waves of light by the particles of the ether; in fact, the density of this agent cannot be changed by ordinary means, the readjustment of equilibrium being so rapid, and the agent completely eludes the grasp, or its existence escapes the direct detection of the senses.

109. It is, therefore, a remarkable and noteworthy fact that the very qualities which serve to conceal the existence of the

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energy and the existence of the pressure, and, indeed, the existence of the agent itself from the direct perception of the senses, are precisely the qualities which are absolutely essential to the existence of this energy and pressure, or the existence of an intense magazine of motion.

It may, in fact, be observed that the existence of an intense store of energy, and the existence of an intense pressure, are not only *consistent* with the fact that the ether is impalpable, but they are the *necessary* consequences of this fact; for the impalpable quality of an aeriform medium is dependent on the rapid motion of its component particles, and this rapid motion cannot exist without the existence of an intense store of energy, and also the rapid motion cannot exist without the exertion of an intense pressure, the pressure, moreover, rising in the high ratio of the *square* of the speed.

110. The existence of an extensive state of subdivision of the matter forming the agent being the essential condition to a high normal speed of the component particles of the agent, this very condition renders the concealment of the motion complete; for by the multiplicity of particles, the mean length of path, or the limits within which the particles can move before being intercepted by other particles, is rendered so small, and the pressure thereby rendered so uniform and perfectly balanced, that the existence of this energy and pressure must necessarily elude direct detection by the senses.

The greatest length of path of an ether particle might well, under the simple condition of subdivision of the matter forming the ether, be contained many times within the limits of space that a molecule of matter would occupy, so that as far as any power of detecting the motion by the senses is concerned, the particles might as well be at rest.

111. *Concealed Motion.*—Since the concealment of the existence of the physical agent from the senses is the necessary result of the enclosure of a store of motion of a high intensity by the agent, and since, as a fact, having a general application, the concealment of motion is the necessary condition to render possible a high intensity of motion, or the enclosure of a store of energy of a high intensity; and, moreover, since the higher the intensity of the energy the more probability is there that its existence should have an important influence on physical phenomena; the investigation of concealed motion, as a general physical problem, should, therefore, have a special interest.

As a known and instructive example of concealed motion which has a considerable intensity, and a most important bearing on physical phenomena, the concealed motion termed "heat" may be referred to.

112. As a known illustration of a physical agent enclosing a considerable store of motion, and exerting thereby a considerable

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pressure, both of which elude the direct perception of the senses, the atmosphere may be cited. The normal speed of the air molecules producing the pressure of 15 lb. per square inch being 1600 feet per second, the energy enclosed, therefore, is such that if a mass of air next the earth's surface were suddenly freed from confinement, the mass of air would explode in every direction, or its molecules would fly apart with the speed of a bullet. The air, therefore, constitutes an instructive example of concealed motion, and may form, as it were, a sort of stepping-stone towards the realization of the ether. If the motion of the air molecules and the attendant pressure be concealed, how much more cause is there for the complete concealment of the existence of the store of motion and the attendant pressure in the case of the ether, the cause for concealment being greater as the moving particles are more minute, and by their multiplicity the motion is confined within narrower limits, and the pressure more evenly balanced? In the case of the air, the moving portions of matter (molecules) are sufficiently small, or the state of subdivision of the matter forming the air is sufficiently extensive, to conceal the motion completely from the senses, and to render the pressure of the air upon masses of matter so perfectly balanced on all sides that the pressure is also necessarily concealed. It may serve to contrast the states of subdivision in the two cases to note the fact of the ether being mechanically suited to exert a uniform pressure about an air molecule (as about molecules generally), while the air can only exert a uniform pressure about a mass (collection of molecules), and would be wholly incompetent to control the equilibrium of a molecule of matter, on account of the absence of an adequate degree of subdivision.

113. When from any cause the motion of the air molecules becomes abnormal, i. e. takes place in any one direction in preference to another, and the equilibrium is thus disturbed, and masses of matter are influenced on one side, then the motion and pressure become very palpable. Such an abnormal motion of the air molecules occurs in the case of a strong wind or hurricane, for example. It may, however, be computed that the energy represented by the translatory motion of the air molecules in the normal state of the air represents an energy about 120 times greater than the energy the air would possess if moving with the speed of a hurricane (taken at 100 miles an hour), and yet the energy and pressure of the air in its normal state remain concealed on account of the perfect state of equilibrium which exists.

114. *Summary of the Physical Qualities of the Ether.*—We may here give a short summary of the special physical qualities of the ether, as serving to show their mutual connection.

I. *Low Density.*—The low density of the ether, or the small quantity of matter contained in the unit volume of space in the case of the ether, is that quality by which the ether is adapted to

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afford free passage to masses (such as the planets, &c.) and molecules of matter, at high speeds, without impediment. Second, this quality renders the ether mechanically well adapted as a means for the general interchange of motion between masses and molecules of matter at a distance from each other, it being an admitted principle of mechanics that for the free interchange of motion, or for the production of any distant effect, lightness in the intervening mechanism is the essential point.

II. *Extreme Minuteness of the Ether Particles.*—This physical quality is absolutely necessary to enable the ether to penetrate with freedom the molecular interstices of matter. Second, this minuteness of the component particles, or extreme state of subdivision of the matter forming the ether, by multiplying the number of the particles, and thereby bringing them into close proximity, is the necessary quality to render the pressure exerted by the ether upon the molecules of matter steady and uniform. Third, this minuteness of the component particles, or extremely subdivided state, is the necessary condition to render a high normal speed for the particles practicable, without disturbing effects.

III. *High Normal Speed of Component Particles.*—This physical quality is absolutely essential to constitute a powerful dynamic agent, for without this high speed dynamic effects of a high intensity cannot be produced. Second, this high normal speed of the particles is the sole condition on which the loss of motion sustained by the ether can be replenished with that degree of speed which is essential to render a continuous dynamic effect of a high intensity possible to the ether. Third, this high speed of the component particles is the sole quality by which the loss of motion sustained by the ether in producing a given dynamic effect can be subdivided or distributed over a large volume of the ether, whereby a notable local disturbance of the equilibrium of the ether is prevented. Fourth, this quality is essential for the rapid interchange of motion between masses and molecules of matter at a distance from each other, the rapidity of intercommunication or exchange of motion being strictly limited by the normal speed of the particles of the intervening agent. Fifth, this high speed of the component particles is necessary to render possible the existence of a store of energy of a high value, without the encumbrance of a large quantity of matter in space. Sixth, the high normal velocity of the ether particles is the necessary mechanical condition to enable an intense pressure to be exerted by the ether upon the molecules of matter, without the movements of these molecules and masses being obstructed by the agent exerting the pressure. For, in the first place, by this high speed of the component particles an intense pressure is attainable (more especially as the pressure rises as the *square* of the speed) without the necessity for the agent being dense, by which the free passage

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of masses of matter through the agent would be obstructed. In the second place, the high speed of the component particles enables masses of matter to pass through the agent with the least disturbance of its equilibrium, or with a minimum of resistance from this cause, the agent becoming almost impalpable; the exertion of an intense pressure by the agent being itself the necessary condition to render the agent adapted to control forcibly the molecules of matter in stable equilibrium, as exhibited in the general phenomena of "cohesion," or the aggregation of the molecules of matter generally.

The above may serve as a general summary of the special physical qualities of the ether; and it may be noted that if the attempt were made beforehand, as a mechanical problem or speculation, to devise or scheme out what special physical qualities an agent should possess in order to be mechanically fitted to produce the varied physical effects of the character observed, then the scheme of the ether would be found to constitute the only possible solution of which the mechanical problem admits; or the ether may be contemplated as a piece of mechanism specially adapted to its work.

SECTION XIV.

115. *Constitution of the Ether; Physical Relations.*—There are some extremely simple relations between the mean length of path of the particles of an aeriform medium, the mean distance of the particles, and the dimensions of the particles. Clausius, who has investigated this subject, and who applied his results specially to gases, has established, mathematically, a relation as regards the mean length of path of a gaseous molecule, which, applied to the case of the ether, would be as follows: The mean length of path of an ether particle is in the same proportion to the radius of the particle (supposing it to be spherical) as the unit volume of space is to the volume of matter contained therein, i.e. the total volume of the particles contained in this unit volume of space.

Since the volume of matter is directly proportional to the number of particles, the theorem might be otherwise stated, viz. that the mean length of path of a particle is greater in direct proportion as the number of particles (of given size) is less. This fact will become tolerably evident on consideration of the subject, for it is clear that the mean length of path, or the distance that a particle can move without obstruction by other particles of the medium, will depend on the number of these obstructing particles,

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the mean length of path of a particle being greater as the number of obstructing particles is less.

It may be further shown to be a result of the above theorem, that the relation between these values, i. e. the values of the mean length of path, mean distance, and the radii* (or diameters) of the particles of an aeriform medium, is constant, whatever the state of subdivision of the matter forming the medium. Now, it is at first evident that the volume of matter cannot be affected by subdivision of the matter, and therefore the relation of the mean length of path to the radius of the particle, which depends directly (as in accordance with the theorem) on the volume of matter, cannot be affected by subdivision of the matter; so that, therefore, the ratio of the mean length of path to the radius of the particle will remain constant, whatever the state of subdivision of the matter of the medium may be conceived to be. If, therefore, we were to imagine a progressive subdivision of the matter of the medium to go on, the radius (or diameter) of the particles and the mean length of path would diminish in precisely the same ratio, the two, therefore, preserving a constant ratio to each other.

It only remains to show that the relation of the mean distance of the particles to these other values also remains constant, whatever the state of subdivision. We may imagine (according to the proceeding adopted by Clausius) space to be subdivided into a number of small cubes, and that at each corner of all these cubes a particle is placed; then any side of a cube will represent the distance of the particles, or the *mean* distance when the particles are placed irregularly, or are in motion. Now, it will be apparent, on considering the question, that by subdivision of the matter of the medium, the side of any one of these cubes and the diameter (or radius) of the particle will diminish in the same ratio. Thus, to take any case: if we suppose by the process of subdivision the diameter of each particle to be halved, then the volume of each particle is thereby reduced to one eighth (the volume of a sphere being as the cube of the diameter), and, therefore, there is now matter available for eight times as many particles; and accordingly, therefore, space may now be further subdivided into eight times as many small cubes, at the corners of all of which particles may be placed. But by this process it will be observed that the side of the cube (i. e. the distance of the particles) has become precisely halved, the length of the side of any one cube being inversely as the cube root of their number. The effect, therefore, of reducing the diameter of the particle to one half by the imaginary process of subdivision of the matter has been to reduce the mean distance to one half; and, therefore, the relation of the

* In the case of the molecules of a gas, *radius* would mean "radius of sphere of action" (as termed by Clausius), i. e. the mean radial distance within which vibrating gaseous molecules, separated by the ether, approach in their mutual interchange of motion.

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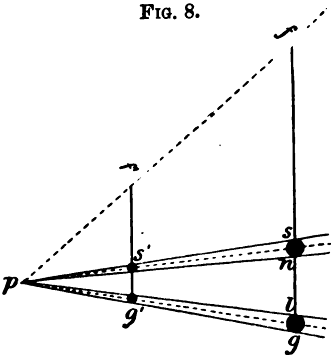
mean distance of the particles to the diameter has been unaffected by the subdivision.

It follows, therefore, that whatever the state of subdivision of the matter of an aeriform medium may be conceived to be, the values of the mean length of path of the particles, the mean distance of the particles, and the diameter of the particles, preserve a constant ratio to each other, and therefore the proportionate (or relative) values would be determined by a knowledge of the proportion of space to matter contained therein, also a determination of any one of these values in absolute measure would determine all. It may be observed that the proportion of space to matter in the medium is evidently proportional to the density of the medium.

There is, accordingly, no limit to the smallness that the values of the mean length of path, mean distance, and diameter of the particles may attain by subdivision of the matter of the medium, all of these values diminishing indefinitely, and preserving a constant ratio to each other as the subdivision progresses.

116. The mode in which these values vary by the process of subdivision of the matter of the medium may be represented graphically in a simple manner. Thus, in the diagram (Fig. 8), if the ratio to the line fs to half sn (radius of particle) represent the ratio of the unit volume of space to the volume of matter contained therein, in the case of the medium, then the lines fs and sn will represent the proportionate values of the mean length of path and the diameter of the particle. If sn and lg represent any two particles of the medium, the line joining their centres (i. e. the prolongation of the line fs) will represent the mean* distance of the particles. Then if lines be drawn from these points to a common point p, any straight line (such as the line $f'g'$) drawn parallel to fg, anywhere between it and the point p, will at its points of intersection represent the values of the mean length of path, mean distance, and diameter of the particles, corresponding to another state of subdivision of the matter of the medium (the parallel straight lines being cut proportionally); these values diminishing indefinitely, and at the same time preserving a constant ratio to each other, as by the progressive subdivision of the matter of the medium, the line fg advances towards the point p.

FIG. 8.



117. The relation of the mean length of path of a particle of

* The proportionate value of the mean distance is here given somewhat too great, for convenience in the diagram, the principle involved not being affected thereby.

an aeriform medium to the radius of the particle being in the relation of the volume of space to the volume of matter (i. e. proportionate to the density of the medium), the known low density of the ether, therefore, makes the influence necessary that the mean length of path, and even the mean distance of the particles, must be a large multiple of their diameters; but on this account the absolute values of the mean length of path and mean distance need not be large, but by the simple condition of subdivision of the matter of the ether, these values may be reduced without limit; as in the illustrative diagram, by the process of subdivision and the attendant reduction of the diameter of the particles, these particles would gradually advance (or slide between the inclined lines) indefinitely near to the point p, carrying the line fg representing the corresponding values of the mean distance and mean length of path, along with them, all the values therefore approaching the vanishing point as the subdivision of the matter of the medium progresses.

The admirable appropriateness of this mathematical relation as a mechanical condition to render practicable the existence of an intense store of energy, and its necessary accompaniment an intense pressure, will be apparent. For the simple condition of an extremely subdivided state of the matter of the medium not only renders a high speed practicable to the particles, by reducing the energy of each almost up to the vanishing point, but this condition has also the effect of curbing the motion within almost infinitesimal limits, and of reducing the mean distance and multiplying the number of particles to such a degree that the equilibrium of pressure even about the small mass of a molecule becomes practically perfect; and therefore the existence of a pressure of an extreme intensity becomes quite practicable, without disturbance of the equilibrium of the molecules of matter, and the consequent concealment of the pressure from the senses becomes complete.

By the reduction of the mass of the particle and the attendant reduction of its mean length of path as a result of subdivision, not only does the energy of each particle taken separately become vanishingly small even when the particle is moving at the speed of light, but the limits of its path almost vanish; or if we regard the limits of path of each particle, the particle might as well be at rest as far as any power of appreciating the limits of its path by the senses is concerned, and yet by the multiplicity of particles attendant on the extreme state of subdivision, and by the consequent addition of the paths of the innumerable particles in their interchange of motion, a wave advances at the speed of light without the motion of the physical links of the chain being apparent; and although by subdivision the energy almost vanishes when each particle is regarded separately, yet the total energy exists to its full intensity.

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SECTION XV.

118. *The Interchange of Motion in the Locomotive.*—We may, as a good illustration, briefly consider the processes involved in the interchange of motion taking place in the locomotive engine. We will regard the state of the case at the point when the steam has been just freshly turned on; then at that instant the molecules of steam, previously in motion and rebounding from each other and from the closed valve of the steam pipe, move along the pipe with their normal velocity on the valve being opened, and impinging against the pistons, transfer part of their velocity to the latter, causing the propulsion of the engine. The loss of motion thus sustained by the steam molecules next the piston is transmitted backwards in the form of a wave, by interchange of motion from molecule to molecule into the steam space of the boiler, the transmission of the wave (or decrement of velocity) being the necessary consequence of the exchange of motion going on among the steam molecules, the rate of transmission of the wave being that of the molecules themselves. This loss of motion, therefore, next affects the surface molecules of the water, and the water thus chilled sinks downwards, thus transmitting the loss of motion to the molecules of the metallic casing forming the heating surface of the boiler. The loss of motion thence passes to the molecules of the fuel next the metallic casing, or the loss of motion is sustained by the store of motion in the furnace, and since the ether is the motive agent of the molecular motion of the fuel, every decrement of motion sustained by the molecules of the fuel is a decrement sustained by the ether, the decrement sustained by the fuel having been previously supplied by the ether, and in this way, therefore, the loss of motion is brought to bear upon the source of motion, the ether.

If this included all the points of the process, therefore, the loss of motion sustained by the molecules of the fuel might have been supplied to these molecules some time previously, the motion having existed in the interval as a store motion in the fuel, ready to be given up at any time. If this, however, were the precise state of the case, the supply of motion by the ether would necessarily be wholly independent of the withdrawal of this motion from the fuel, or the two processes would go on quite independently of each other; and if this were the case, the amount of motion supplied by the ether to the fuel would be quite independent of the fact, whether this motion was utilized (expended) or not, i. e. the ether would continue to supply motion quite independently of the fact whether there was a demand for motion or not. Now, it may be shown that this is not the actual case, but

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that by a special process the supply of motion by the ether becomes to a certain extent adjusted to the demand, or a rapid drain of motion from the fuel (i.e. from the freshly combined molecules of carbon and oxygen) brings the ether into augmented action, and when there is no demand for the motion of the fuel the energy of the ether is held to a certain extent in reserve. In order to follow this process we must consider certain points.

119. It is a known fact that an elevation of temperature beyond a certain degree tends to separate chemically combined molecules (and, indeed, molecules generally), and by a due elevation of temperature the molecules are completely separated ("dissociated"), or an excessive degree of vibrating energy is unfavourable to the stable union of the molecules, or, as before alluded to, a certain degree of vibrating energy exists which is the best adapted to effect a reduction of the ether pressure between the molecules, causing them to approach with maximum energy. When, therefore, the temperature of combined molecules is raised beyond the point which corresponds to the maximum stability of their union, the molecules commence to recede from each other, the molecules at last separating completely at the temperature of dissociation. When, conversely, the temperature of molecules is beyond the temperature of dissociation, a lowering of the temperature may be followed by a combination of the molecules, the molecules afterwards gradually approaching into closer proximity as the excessive vibrating energy is gradually reduced.

Thus, if we take, for example, the case of the combination of the constituent molecules of carbon and oxygen to form a compound carbonic acid molecule in the combustion of coal, then the high velocity with which the pair of vibrating molecules in their approach are driven against the intercepted oscillating ether column intensifies so greatly the vibrating energy of the column that the molecules are temporarily checked by their own rapid approach; and as the excessive vibrating energy is gradually dissipated in the surrounding ether, the molecules gradually approach into closer proximity. But this approach of the molecules, in which act the pair of vibrating molecules are slowly urged by the ether pressure against the intercepted vibrating ether column, is necessarily attended by fresh increments of vibrating energy in the molecules, so that, in fact, the molecules cool more slowly than would otherwise be the case; and instead of all the vibrating energy (heat) being developed and concentrated in the first act of approach of the molecules, a part of the heat is subsequently generated; but, as an important point, this subsequent generation of heat is entirely subject to the condition that the heat first generated is drawn off or utilized; for unless this be the case, i.e. unless the vibrating energy of the molecules change (by the loss of heat), the molecules will necessarily remain at a fixed distance from each other, suited to their special degree of vibrating energy, and the molecules

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would not approach into closer proximity at all unless their vibrating energy were changed, i. e. unless their heat were drawn off; so that, therefore, by the absence of demand for heat, the energy of the ether is held in reserve; and conversely, by a rapid drain upon the heat, the molecules would rapidly take up their final positions of proximity due to normal vibrating energy, and thus the ether, by urging the vibrating molecules into closer proximity, follows up the demand for heat by a fresh supply.

120. By this special process the work of combustion is greatly equalized, and instead of the intense initial heat that would result, were all the heat developed in the first instant of combination of the molecules, the initial heat is moderated, and the development of heat equalized by being spread over a certain period of time. By this process the action of combustion, as in the case of the locomotive, for example, is brought to bear against, or is spread over a larger surface, and instead of all the heat being concentrated to an excessive amount in the furnace itself, which would possibly be detrimental to the constructive materials, a portion of the heat is generated in the tubes of the boiler, or an incandescent carbonic acid molecule in its progress through the tube develops fresh increments of vibrating energy, by the gradual approach of its pair of components under the action of the ether, as the vibrating energy of these components is gradually expended in the progress of the molecule through the tube. The compound molecule forms, therefore, an extremely sensitive piece of mechanism, the slightest change of temperature (change of vibrating energy) causing a readjustment of the distance of its pair of components relatively to the intercepted vibrating ether column, whereby the ether comes into fresh action.

From these considerations it would also follow that the escape of products of combustion at a high temperature is not only wasteful on account of the absolute heat being thus lost, but also on account of the fact that the additional heat generated as the lowering of the temperature proceeds is also lost.

The turning on of the steam in the case of the locomotive, followed by the continued chilling of the extensive surface of the flue-tubes by the continued evaporation of the water as the engine proceeds, therefore brings the ether into fresh action in the flues, whereby combustion is more complete than would otherwise be the fact, and thus the demand for heat by a self-acting mechanism brings the ether into action, causing a fresh supply.

121. We may perhaps just note here, in connection with this subject, that this special deportment of aggregated molecules admits of being illustrated by a case in which the effect is actually visible. For the effect to be visible it is clearly only necessary that the molecules should be aggregated in sufficient numbers as to multiply the effect of each pair of molecules, and thereby render the effect visible. Thus the abstraction of heat from a heated bar

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of metal, for example, is followed by a closer approach of each pair of molecules forming the bar (the contraction of the bar being measurable) under the action of the ether, whereby each pair of vibrating molecules is slowly but forcibly urged against the oscillating ether column intercepted between them, a fresh development of vibrating energy in the molecules being the result, or more heat must be abstracted from the bar in order to lower its temperature to a given degree than if the bar did not contract (i. e. if its molecules did not approach), this additional quantity of heat being precisely that developed by the ether in effecting the approach of the molecules. The effect is of course relatively feeble here compared with the effect in the case of the more intimate grouping of dissimilar molecules about a common centre to form compound molecules (chemical union), the effect being greater in proportion as the energy of chemical combination is greater, and also in proportion as the range of temperature to which the molecules are exposed is greater. Thus, to form a just appreciation of the effect in the illustrative case given of the locomotive, we must take into account the energy of the approach of molecules in combustion, and also the extreme range of temperature to which the products of combustion are exposed.

It may also be observed that in a perfectly analogous manner the aggregated molecules of the metallic bar may be dissociated, or completely separated, by a due elevation of temperature.

122. In the interchange of motion taking place in the locomotive, it forms a point of interest to observe how in mechanical conformity velocity is apportioned to mass, or we have the extremely rapid motion of the minute ether particles, the slower motion of the larger masses constituting the molecules of coal and steam, and the still slower motion adapted to the large masses forming the visible part of the mechanism. Also the transference of motion takes place step by step by a gradual process, the motion passing first from the minute but rapidly-moving ether particles to the relatively large masses of the molecules of coal, the motion passing thence through the intervention of the molecules of steam, to the massive and slowly-moving pistons.

In the inverse process by which the motion is returned to the ether, or to its original source, the transference of motion takes place in the same gradual way, the motion passing from the massive moving parts of the engine to molecules, as represented by the heat developed in the working parts, the motion passing from these molecules to the ether in the form of waves (by radiation). The escaping steam and gaseous products of combustion whose residual motion has not been transferred to masses, lose this motion by transference to the ether; and thus the motion derived from the ether is being continually returned to the ether during the progress of the engine. The process involved is therefore a cyclical one, consisting in the transference of motion from the

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ether through matter to the ether; or the process involved in the case of the locomotive, viewed fundamentally, consists in the ingenious disposal of a train of matter under such physical conditions that this train of matter takes motion from the ether at one end and returns the motion to the ether at the other end. A fundamental principle of extreme simplicity, therefore, underlies the complexity of the mechanical arrangement.

123. It is a very firmly grounded idea that simplicity should exist in the working of physical phenomena, or that physical processes should be simple. Now, although the existence of this simplicity is an undoubted fact proved by experience, the existence of a strict cause for this is not perhaps so generally recognized. Without attempting at all to go fully into this question, we think that at least one determining cause for this simplicity may be pointed out. A physical process resembles, and indeed may be defined as, a mechanical process. Now, in all the mechanical processes of industry, as in constructive mechanics, or in any case whatever where a mechanical means or adaptation is applied to an end, simplicity is actually recognized as the governing principle. The whole aim of constructive mechanism is directed towards simplicity, as in the case of the locomotive, for example; the advance towards simplicity constitutes one of the main stages of its progress. The real fact is, that the end is not otherwise attainable except under the condition of simplicity, for if a mechanical adaptation or machine be not simple, or if it have more parts than are absolutely essential to the intended purpose, the machine will not fulfil its intended purpose, i. e. it will not perform its functions in a proper and orderly manner. To have, therefore, order in the working of any mechanical process, or means to an end, simplicity may be said to be a necessary condition. If, therefore, order be observed to exist, the existence of simplicity may be deduced therefrom. It is, therefore, not a mere question as regards superfluity, or that simplicity is desirable because superfluity would be in vain, but the end is not attainable at all excepting under the condition of simplicity. It would follow from these considerations that simplicity in physical phenomena may properly be regarded as the absolutely necessary condition to the attainment of the observed results, or as the essential condition to the proper and orderly working of physical phenomena.

In the case of the locomotive, for example, simplicity, or no superfluity of parts, must be as essential to its molecular mechanism (i. e. the mechanism of the coal, ether, and steam) as to its larger scale mass mechanism, for mere dimensions or size cannot affect the principle evolved, the larger scale mass mechanism being itself composed of the very same parts of which the molecular mechanism consists, for the mass mechanism is all made up of molecules surrounded by the ether. Hence we may expect

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to find simplicity and no superfluity of parts in the molecular mechanism of the locomotive; nevertheless it is just as essential that this mechanism of the vibrating molecules of coal and the ether, with their mutual interchange of motion, should have connected parts and should form a connected whole, as that the larger scale mass mechanism should have connected parts and should form a connected whole, for the principle of reasoning and the method of viewing the subject cannot in any way be affected by a change of dimensions of the mechanism. The molecular mechanism of the locomotive, minute in detail but vast as a whole, may indeed be regarded as the main part of the mechanism, for there the motion originates. The mere outer shell and appliances of the locomotive without the mechanism of the action of the ether upon the vibrating molecules of coal, might be compared to the outer shell of a flute with its arrangement of keys without the hidden mechanism of the air, which by its stationary vibrations in columns of varied length is the real source of the sound, the outer shell of the flute fulfilling a purely subsidiary part.

It might also have been observed above, in connection with the subject of simplicity, that the beauty of simplicity consists in its uniqueness; for while there are an indefinite number of ways of attaining a result or mechanical end by a complicated method, there is but one way of attaining the result by a simple method, which therefore entails a special exercise of the intellect to find it.

124. Steam owes its handiness and power as a dynamic agent to the physical qualities of a rapid motion of its component molecules combined with lightness (i.e. small quantity of matter relatively to the unit volume of space); and just as these special physical qualities exist developed to a far higher degree in the case of the ether, so the ether is by so much superior to steam as a dynamic agent. Steam evidently cannot be looked upon as a true dynamic agent or source of motion, since steam only becomes a dynamic agent after the motion to be utilized has been imparted to its molecules. The ether, on the other hand, is a true dynamic agent or source of motion, since the ether in its normal state already encloses a store of motion. In the case of the locomotive, therefore, the motion cannot be said to be derived either from the steam or the coal, since the former is not a dynamic agent, and the coal has no motion to impart. The motion can only be derived from a source where motion exists, i.e. from the ether, whose normal state is a state of motion; the coal and steam simply forming convenient pieces of intervening mechanism by which the motion of the ether is transferred to the pistons, just as the connecting-rod, for example, is the convenient piece of mechanism by which motion is transferred from the pistons to the wheels.

125. *The Energy of Combustion.*—It is a known fact that the

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dynamic value of the combustion of one pound of coal (carbon) amounts to about eleven million foot-pounds. From this it may be computed that the intensity of the energy developed at the combustion of coal is such that it would be competent to project the mass of coal and oxygen taking part in the process to a height of not less than 570 miles.

Now, regarding this remarkable fact as any other mechanical question or engineering problem, and with the view to form a practical realization of the means by which this result is attained, or the mode in which this amount of energy can be brought to bear against the coal, such as the coal filling the furnace of a locomotive, for example, it is well to keep practically in view the important peculiarity of the *molecular* state of matter, by which a vast extent of *surface* is brought under the dynamic action of the ether, the ether pervading the entire mass of coal which fills the furnace, and surrounding each one of the innumerable molecules of the mass. If we take a single cubic inch of coal and imagine it spread out into a layer, one molecule in thickness, some idea may perhaps be formed of the amount of surface that must be exposed. If we suppose that a carbon molecule would be contained within the limits of $\frac{1}{10,000,000}$ inch, then such a layer of coal would cover upwards of one acre and a half. This estimate is merely intended to give a rough idea of the vast extent of surface that must be exposed, the estimate being probably less than the actual fact, since the above assumed value for a molecular dimension is almost beyond question too great.

If, therefore, this represent the surface exposed by a single cubic inch of coal, what must be the vast extent of surface exposed by the mass of coal which fills an ordinary locomotive furnace? If we figure to ourselves this vast extent of surface brought under the play of the intense ether pressure, or these innumerable molecules of carbon brought under the intense dynamic action of the ether which pervades the furnace, then the intense energy of combustion will reconcile itself with ordinary mechanical principles, and even become a necessary deduction following these principles.

126. *Movements of Animals.*—It is a recognized fact that a fixed relation exists between the movements of the animal body or the work performed, and the chemical processes taking place within the animal system, the work performed being the exact mechanical equivalent of the energy developed at the oxidation of the food; the animal system in this respect, therefore, precisely resembling a mechanical motor, such as the steam engine, for example, where the work performed is the exact mechanical equivalent of the energy developed by the combustion (oxidation) of the coal, including of course under total work, in both cases, the attendant dissipation of a portion of the energy in the form of heat.

The ether being the physical agent concerned in chemical pro-

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cesses generally, whether in the oxidation of the food in the case of the animal body, or in the oxidation of the coal in the case of the steam engine, the ether therefore must constitute the original source of motion in the case of the animal system, as in the case of the steam engine, and that of mechanical motors generally.

In a perfectly analogous way the entire work done by the animal system goes in its final stage to the ether (in the form of waves of heat, &c.), i. e. to its original source in a cyclical process. However complex and varied, therefore, the molecular processes and changes may be which take place within the animal system in the passage of the motion through its intermediate stages, and however difficult it may be to follow the motion through the entire cycle, it is none the less certain that the ether is the primary source and final receptacle of the motion.

SECTION XVI.

127. *The Identity of Physical Processes in their Fundamental Nature.*—We have observed that all physical processes are identical in one fundamental respect, in that they all consist in an *interchange of motion.* The *interchange of motion* may therefore be said to constitute the *simple* groundwork or fundamental principle upon which all physical phenomena in their vast variety are based, and in this one circumstance the necessary correlation of all branches of physical science lies apparent. The fundamental principle is itself simple, yet, from its very nature, consistent with the production of phenomena of endless variety. The *interchange of motion* may be said to form the whole basis of the great principle of *conservation,* for the very idea of the *interchange* or *transference* of motion itself precludes all idea of the possibility of the annihilation of motion; or the only possible method of getting rid of the motion of a mass of matter is by *transferring* that motion to another mass or masses.

128. We shall now proceed to consider more closely the mode or general principle upon which physical processes effect themselves, and it will be our endeavour to show that these processes resemble one another in a second fundamental aspect, viz. that all these processes are *cyclical,* i. e. consist in a transference of motion from the ether through matter to the ether, or consist in a transference of motion from and to the same source; and therefore that all physical processes, however diverse and varied, are identical in this fundamental respect; or that every observed motion whatever came from the ether at one time, and will return to the ether at some subsequent time.

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This theorem may be shown to be a necessary consequence resulting from the fundamental principle of conservation. The normal state of the ether is a state of motion, or the component particles of the ether transfer their motions among themselves, and this motion is of necessity permanently maintained. The ether, therefore, constitutes a *source* of motion. A mass or molecule of matter, on the other hand, cannot possibly be in motion without continually giving up some of its motion to the surrounding ether, which motion is rapidly carried off to a distance in the form of waves; so that matter cannot possibly remain in motion, unless the motion be renewed by the ether as rapidly as it is being dissipated in the ether, which would constitute a *cyclical* process. Since, therefore, the motion of matter is being continually dissipated in the ether, the ether constitutes the *receptacle* of all the motions of matter. The ether therefore must, in accordance with the principle of conservation, be the *source* of all the motions of matter, for matter cannot evolve motion out of itself. Also, since matter cannot retain its motion, but must be always dependent on the ether for any supply of motion, matter therefore cannot in any case constitute a *source* of motion. *The ether therefore constitutes both the source and the receptacle of all the motions of matter*, or this would constitute the theorem that all physical processes are *cyclical*, or consist in a transference of motion from and to the same source, and accordingly that all physical processes are correlated in this fundamental respect.

129. It is obviously not necessary that all motions should come *direct* from the ether, but an observed motion may have been transmitted through matter since its original derivation from the ether. Thus, for instance, there may exist a store of motion originally developed by the ether in matter, and from this store of motion the observed motion may directly come. The sun, for example, constitutes such a store of motion. Any observed motion of a mass or molecule, therefore, traced backwards in the first instance to the sun, is simply a motion which in its passage from the ether to the mass or molecule has been transmitted through the sun as an intervening link in the cyclical process, the motion afterwards passing from the mass or molecule to its original source, the ether.

Again: it is quite evident that an observed motion need not pass to the ether direct, but this motion may undergo several transferences through matter first. But it is clear that such a process must have a limit, for any attempt to retain motion in matter, or to prevent the passage of the motion to the ether by transferring the motion from one mass or molecule of matter to another, would only render the passage of the motion to the ether the more rapid, for during the whole process, and more especially at every such interchange of motion between masses and molecules, a portion of the original motion is necessarily

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dissipated in the ether in the form of waves of heat. In tracing, therefore, conversely, a motion backwards, there is a distinct limit to the number of times this motion can have been transferred through matter, for the number of transferences a motion can undergo without complete dissipation must be limited by the original value of the motion. Hence, although a motion, observed at any point of its progress, may have undergone several transferences through matter since its original derivation from the ether, and this motion may in certain cases undergo several such transferences before passing finally to the ether, the process is nevertheless in all cases a cyclical one, or the motion comes from and passes to the ether.

130. We shall now refer to some practical examples illustrative of the above theorem. The main adaptations for the derivation of power may be classed as steam, the utilization of the fall of water, the utilization of winds, and the work of animals. In all these cases the physical processes involved may be shown to be identical in principle, or the processes are cyclical, consisting in the transference of motion from the ether through matter to the ether.

In the case of the steam engine and the animal system, already treated of, the energy derived from the ether in the combustion (oxidation) of the coal and food in the two cases, passes to the ether in the various operations performed, the withdrawal of motion from the ether and its transference to the ether going on simultaneously.

131. The "fall" (approach) of masses ("gravitation") resembles the approach of molecules as regards the physical process involved. When, therefore, the fall of water is utilized for mechanical purposes, the motion developed in the water is derived direct from the ether, and is transmitted by the water through the machinery to the ether (in the form of waves of heat developed in the working parts of the machinery, &c.), the process involved being a cyclical one, in which the derivation of motion from and its transference to the ether go on simultaneously.

132. The production of winds may be referred in general to the adjustment of differences of pressure in the atmosphere, these differences of pressure having been brought about by differences or changes of temperature. This adjustment of differences of pressure being directly due to the action of gravity, the motion of the current of air and of the current of water may therefore be brought under the same physical cause, i. e. the direct action of the ether. By the utilization, therefore, of winds for mechanical purposes, the air current forms the convenient mechanical adaptation by which the motion of the ether is transmitted to the machinery, the motion passing in the various operations of the machinery to the ether in a cyclical process.

In regard, therefore, to the four principal means for the deriva-

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tion of power, viz. steam, currents of water, currents of air, and the work of animals, the physical processes involved may be all classed as identical in principle, the processes being *cyclical*, consisting in the simultaneous withdrawal of motion from and its transference to the ether.

133. The formation of coal was due, as is known, to the action of the sun's rays upon the molecules of carbonic acid, by which the components of the compound molecules were separated, the carbon being deposited in the vegetation, becoming eventually the food of the animal and the fuel of the steam engine. At the separation of the molecules, therefore, by which the carbon was deposited, the work was done by the ether waves (sun's rays) on the ether, or the amount of motion lost by these waves was equal to the amount of motion imparted to the ether in the process of separating the molecules, and in which the work of separation consisted. In this case, however, the ether could not be said to be, *at the time*, the source of the motion which separated the molecules, since at the time of separation the ether was only the transmitter of that motion from the sun; and therefore this case is in one respect different from the reverse case of the approach of the molecules (combustion), when the ether is, *at the time*, the source of the motion of approach of the molecules, or the derivation of motion from and its transference to the ether go on simultaneously. The ether was, nevertheless, the source of the motion which separated the molecules, or the process formed a cyclical one of the special character already treated of, i. e. a cyclical process in which the motion derived from the ether has, in its passage to the molecule, been accumulated in the interval as a store of motion in matter; or the ether, as the original source of the sun's heat, was thereby the source of the ray which separated the molecules, the separation of the carbon molecules at the production of coal having therefore formed part of a *cyclical* process, in which the development of the sun's heat formed an intervening link.

Precisely the same considerations apply to the case of the elevation (separation from the earth) of the molecules of water, under the action of the sun's rays, to form eventually water currents (streams); and to the case of the elevation of the molecules of air under the action of the sun, to form eventually air currents (winds); or the process involved in the elevation of the molecules in the two cases is a cyclical process, in which the motion in its passage from and to the ether was accumulated for a period in matter (the sun) as a store, and therefore the derivation of the motion from and its transference to the ether are necessarily not *simultaneous*.

134. As regards, therefore, the separation of the molecules of carbon which deposited in the vegetation becomes, in the form of animal food and coal, an adaptation for the derivation of power in two important cases; and as regards the elevation of the mole-

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cules of water and air, which also become adaptations for the derivation of power, the physical processes involved in all these cases are identical in principle among themselves, or the processes are all *cyclical,* in which, however, the motion derived from the ether has been accumulated as a store in matter during its passage from and to the ether; and therefore the derivation of the motion from and its transference to the ether do not take place simultaneously.

On the other hand, the physical processes involved at the derivation of the power, i. e. at the oxidation (combustion) of the carbon in the animal system and in the steam engine, and at the movement of the molecules of air and water in the form of winds and streams, are also *cyclical* processes, identical among themselves, but in one respect different from the previous processes, in that the motion comes direct from the ether at the time, or the transference of motion from and to the ether goes on *simultaneously.*

SECTION XVII.

135. *Amount of energy being dependent on the quantity of matter in motion and on the square of the velocity of motion,* and since motion cannot come into existence spontaneously, or go out of existence spontaneously, but in accordance with the principle of conservation, the sum of energy must remain constant; it follows, therefore, that whenever there is a loss of motion by matter, there must be a simultaneous gain of motion by matter, or the loss and gain of motion must be *simultaneous,* for a loss of motion without a simultaneous gain of motion would involve for an interval of time an annihilation of energy.

It follows, therefore, as a necessary consequence from this, that the energy expended in any physical process whatever can be solely dependent on and due to motion simultaneously imparted, i. e. imparted *at the time* of the expenditure of the energy; for unless motion be imparted at the time, energy cannot be expended at all, for to expend motion without imparting motion would be to annihilate energy; indeed, the motion imparted is itself the measure of that expended, and is the sole cause of its expenditure, i. e. motion can only be expended in the communication of motion, and in that fact lies apparent the principle of the *Indestructibility of Motion.*

136. Physical processes accordingly consist in an interchange of motion. "Work," which admits of but *one* definition, consists, therefore, in every possible case in the *communication of motion.* When the object is to check motion, a "resistance" is applied. A

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"resistance" has but one character, and consists in a means or adaptation for the transference of motion. It may serve, therefore, well to illustrate the principle of the indestructibility of motion, to note the fact that the very means applied to extinguish motion, or a "resistance" itself, is a direct means for communicating motion, or the only possible means of getting rid of motion is by communicating motion. The most effective railway brake, for example, is that through which, in a given time, the greatest amount of motion is communicated in the form of molecular motion ("heat").

137. *Reverse Processes.*—Since the amount of energy expended in any physical process is solely dependent on the amount of motion imparted at the time of the expenditure of the energy, it follows that the amount of energy interchanged in any physical process can have no necessary connection with the amount interchanged in another process, but the amount of energy interchanged in any physical process is dependent solely on the physical conditions involved in that process. Whether, therefore, two physical processes happened to be equivalent to each other or not would depend on the physical conditions involved in each.

In reverse physical processes generally, i. e. by the approach and recession of masses and molecules of matter, there is an obvious general similarity in the physical conditions, since the masses and molecules in the two reverse processes traverse precisely the same path, under the same circumstances. Hence it would be reasonable to expect a certain equivalence to exist in the quantities of energy interchanged in the two processes. There is, nevertheless, one important exception to the similarity of the physical conditions which we shall consider. Thus, for example, in the case of chemical decomposition and recomposition, when two vibrating molecules are moved from each other, the ether which resists the motion and upon which the work is done, is necessarily to a certain extent condensed, by an amount dependent on the velocity of recession of the molecules. Owing, therefore, to the condensation, the number of particles to which motion is imparted is correspondingly increased, and accordingly the work done in separating the molecules is increased from this special cause. On the other hand, when two molecules are urged towards each other, the ether which does the work is (conversely) to a certain extent rarefied, since the movement of the molecules takes place in a direction from the portion of the ether which does the work. The number of particles in action being thereby reduced, the work done at the approach of the molecules is thereby reduced. Since, therefore, this special physical cause acts conversely in the two reverse processes, or contributes to increase the energy to be expended at the separation of molecules, and to reduce the energy to be derived at the approach of molecules, and since, however slowly the motion of the molecules might take place, this physical cause

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must have its corresponding effect, it follows, therefore, that in mathematical strictness two reverse physical processes never can be equivalent. The degree of nearness of approach to actual equivalence would depend upon the relation existing between the normal velocity of the ether particles and the velocity with which the movements of matter in the reverse processes take place. Since the ether particles happen to have a high velocity, and the movements of molecules in chemical action are in no case comparable to the normal velocity of the ether particles, the two reverse processes must therefore approach nearly towards absolute equivalence, or the difference is not sufficient to have made itself observable. The accumulated differences of such processes, however, by continual repetition, in course of time must reach an important amount. The most likely case to attract the observation would be one where the motion takes place at a high speed and over long distances, as, for example, in the case of cosmical matter propelled by the action of the ether in "gravitation," where, on account of the long-continued action through great distances, the final speeds attained are much greater than in the case of molecules propelled by the action of the ether in "chemical action." It is a significant fact that comets in their alternate swing of approach and recession from the sun in their eccentric orbits, lose velocity, and shorten their paths by palpable amounts.

138. If by any device the performance of work on the ether at the recession of molecules could be avoided, then no expenditure of energy would be required in separating the molecules; just as, conversely, if the action of the ether at the approach of molecules could be prevented, no energy would be derived from the approach of molecules.

It is well to observe that the work done on the ether at the separation of molecules is completely useless work, serving no practical object whatever, since the motion thus imparted is carried off beyond all power of utilization; indeed, since whatever means be used to separate the molecules, whether through the intervention of heat or chemical agency, the ether (as the motive agent concerned in these two cases) itself does the work of separating the molecules, or the process is a cyclical one, consisting in the transference of motion from and to the ether; it is therefore clear that it would not affect the absolute sum of motion in the least if no such interchange of motion took place, or if the molecules were simply caused to recede from each other without the ether coming into action at all. This is, therefore, not a question affecting in any way theoretic principle, but simply a question as to the practicability of a device to avoid the performance of useless work; and if such a device were practicable, the components of the molecules of carbonic acid, for example, would separate without the performance of work, and the carbon would thus be available

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to be burnt a second time by the action of the ether. If this device were practicable, there would not be the slightest absolute gain of motion by it, for a mass of coal or carbon is simply a machine, and cannot evolve motion independently of a source of motion, or a mass of coal is simply a piece of mechanism for utilizing the motion of the ether, just as, for example, a waterwheel is a piece of mechanism for utilizing the motion of a stream; or all the motion developed at combustion, and imparted to the ether in the form of waves of heat, comes from the ether at the time of combustion, so that the process of combustion might be continued indefinitely without the slightest absolute gain of motion, or the interchange of motion constituting combustion is quite independent of the fact whether energy was expended in the previous act of separating the carbon or not. If the vibratory motion of molecules could be brought under control and thus be temporarily got rid of by utilization in any way, then the above result would be attained, or the molecules would separate without the performance of work; as we have before pointed out that there are certain considerations which would indicate that this result is actually attained in nature, in the disintegration of matter at a low temperature. Thus, for example, this result is actually attainable in the case of vibrating masses where the vibrations are under control.

If, for instance, we take the case of a vibrating mass, such as a tuning-fork maintained in vibration by some external source of power, just as a molecule is maintained in vibration by the ether waves emitted by the sun; then, if we suppose a piece of card to be placed near the fork, and the vibrations of the fork to be temporarily checked by any means, then the card may be separated or removed from the fork without the performance of work. If then, while the card is now at a certain distance from the fork, the latter be allowed again to vibrate, the card is attracted or urged towards the fork, and this separation of the card without the performance of work, and return of the card under the action of the air, whose moving molecules constitute the source of motion, might thus be repeated any number of times. Here, by a simple device, the performance of useless work in separating the card, or the performance of work in direct opposition to the source of motion (the air), is avoided. The same considerations apply in the case of vibrating molecules, the separation of which without the performance of useless work, or the performance of work in direct opposition to the source of motion (the ether), is a question merely depending on the practicability of the application of a device, and not a question affecting in any way theoretic principle.

139. The motion of a permanent source of motion can always be made available provided the machinery be applied and used in a proper manner. The machinery of nature for deriving motion from the ether all works on the simple reciprocating principle of approach and recession. A movement of approach must come to

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an end, so that the problem is to reverse the movement without performing work in direct opposition to the source of motion. By all the engineering appliances for deriving motion from subsidiary sources, this device for reversing the movement is applied and recognized as the absolutely essential condition. Thus, in the case of the steam engine, for example, where motion is derived from the subsidiary source, steam, a device is applied to reverse the movement of the piston without performing work in direct opposition to the source of motion (the steam), and without this device it would be necessary either to force the piston back in direct opposition to the steam pressure, whereby the energy expended would be as great as that derived, or else the piston would only make one stroke, and then become useless. Now, this is precisely what is the case with the molecular mechanism of the steam engine according to the present system of application and use, or the molecules of coal make one stroke (approach once) under the action of the ether pressure and then become useless, and thus, while the larger scale portion of the mechanism of the steam engine (the mass mechanism) is stationary, or is used again and again, the molecular mechanism is subject to continuous renewal, and, in fact, we have the anomaly that the power derived is proportional to the *machinery* expended. By the absence of a device for reversing the movement in the case of the molecular mechanism, the molecule of carbon must, in analogy with the piston in respect to the steam pressure, either be forced back in direct opposition to the intense ether pressure, or else the molecule can only approach once, and therefore a separate molecule is required for every stroke, as in analogy in the case of the larger scale mechanism, if there were no device for reversal a separate piston would be required for every stroke. This expenditure of mechanism clearly cannot affect the motive power derived from the source of motion, but it is inconvenient from the fact that the stock of coal is not infinite. The simple means of reversal as it takes place in nature, by dissipation of the vibrating energy of molecules in the ether by the isolation of matter, cannot be adopted, since there is no means of isolating matter, and all substances on the earth's surface are vibrating with intense energy. Perhaps a partial reduction of the vibrating energy might help, but we are not restricted to discrete molecules, and possibly the reciprocating movements of approach and recession of masses under the action of the ether in the "electric" and "magnetic" phenomena might be found more subservient to this special object, and thus the enormous stores of motion present on all sides be made of more practical avail than by the present methods of utilization. At all events, it appears an anomaly that motion should be only obtainable from a source on the condition of the expenditure of an equivalent amount of machinery.

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SECTION XVIII.

140. We may now, as a further practical illustration of the theorem that all physical processes are *cyclical*, consider briefly some of the various industrial operations, or we may take the case of the varied operations of a steam factory for example. Here, after the different machines are in full movement, and the work has assumed its normal value, and there is no further acceleration or accumulation of motion in matter; then it follows that from this point the motion must be in the process of being transferred to the ether as rapidly as it is being derived from the ether. The test of perfect equality in the motion derived from and given to the ether is the continued uniform rate of motion of the machines through which the motion passes in its intermediate stage; for if the motion given up to the ether were less than that derived, there would be an accumulation of motion in matter, or the machines would be accelerated, the converse being the case if the motion given up were greater than that derived. Hence, when the machines are in full movement the derivation of motion from and its transference to the ether take place simultaneously in a cyclical process. It may be noted that at the particular instant when the machinery was first started, motion was derived from the ether without being simultaneously transferred to the ether, this relatively small amount of motion (representing the motion of the machines) remaining abstracted from the ether so long as the machines are in motion, but when the machines stop, this motion is returned to the ether (in the form of waves of heat), the machines coming to rest by converting their motion into heat.

When, therefore, the machinery, including the mechanism of the coal and engine, is in full action, the surrounding ether must be simultaneously pervaded by two wave systems; the one system consisting on the whole in an excess of motion imparted to the ether, this system comprising the waves generated in the ether by the vibrating molecules of matter as a large portion of the motion derived is converted into heat, including both those waves of wasted heat, or the motion (heat) which is transferred direct to the ether by the coal without having *previously* been transmitted through the machinery, and the motion of the coal which after transmission through the machinery is converted into heat in the mechanical operations taking place. This wave system also includes, as an important part, the increments of motion given to the ether particles in the various kinds of work, such as by the displacement of the molecules of materials, &c. The second of the two wave systems consists on the whole in a loss of motion sustained by the ether, as represented by the decrements of velocity sustained by the particles of the ether as the motive agent

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of the molecular motion taking place in the boiler furnaces represented by the combustion of the coal; the decrement of motion in the one wave system being precisely equal to the increment of motion in the other wave system. The quantity of energy in the ether is therefore, on the whole, neither increased nor diminished by the progress of the work, but the ether is merely broken up into waves representing an interchange of motion going on in the surrounding ether, which is the indication of the interchange of motion going on in the machinery, which latter forms only an intermediate link of the complete chain. That the quantity of energy contained in the ether is unaffected by the progress of the work, follows also at once from the principle of *conservation* in accordance with which the collective sum of energy contained in the ether and in matter must remain constant. So long, therefore, as the energy of matter represented by the uniform motion of the machinery remains constant, the energy contained in the ether must also remain constant, for otherwise the total sum of energy would be changed. The ether, therefore, being the source and receptacle of the motion, its component particles are affected by increments and decrements of velocity, these changes of velocity being extremely small compared with the normal velocity of the particles, the ether by the interchange of motion going on among its particles, tending continually to assume its normal state of equilibrium of motion, the small changes of velocity being rapidly carried off in the form of spherical waves, by whose expansion the changes of velocity are soon dissipated by subdivision.

141. Since work consists in the *communication of motion*, and since no kind of work consists in the continual accumulation of motion in matter, it is clear that in every kind of work, as previously deduced, the motion expended must pass to the ether. Even if it served any practical end, it would clearly be impossible to accumulate motion continually in matter, for the greater such accumulation of motion, the more rapid is its passage to or dissipation in the ether, so that a stage must soon arrive at which the motion dissipated in the surrounding ether equals that expended. Accordingly, every possible kind of work will be found, when analyzed, to consist in the communication of motion to the ether, either directly or in its final stage. Thus, for example, in all the varied operations of shaping materials, whatever their nature, such as the operations of planing, shearing, &c., in which act the vibrating molecules of substances in stable equilibrium with the ether pressure are forced out of their positions of equilibrium, the work consists in the communication of motion to the ether, the rapid dynamic action of the ether particles entailing a large amount of work at the displacement of the molecules.

The process of coiling a spring, as by the winding up of a clock, for example, in which act the vibrating molecules of the spring are displaced, affords another illustration of work consisting

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in the communication of motion to the ether. If the spring be coiled through animal agency or through the intervention of a steam engine, then the motion given up by the ether in transmitting motion through the animal system, or through the mechanism of the coal and engine, to the molecules of the spring, is equal to the motion imparted to the ether by the molecules of the spring in the act of being coiled, or the process is a cyclical one, consisting in the transference of motion from and to the ether. Conversely, when the spring uncoils, and communicates motion to a clock, for example, then the motion expended by the ether in urging the molecules of the spring back into their former positions of equilibrium, is equal to the motion imparted to the ether in the form of waves of heat developed by friction in the working parts of the clock; or the physical process is a cyclical one, consisting in the transmission of motion from the ether through a train of mechanism to the ether.

Thus all the commonest operations and phenomena occurring in everyday experience constitute illustrations of the *theorem that all physical phenomena are fundamentally correlated as cyclical processes consisting in an interchange of motion, and in which the motion is derived from and passes to one universal source of motion, the ether.*

142. Since to develop a given power, the dimensions of a mechanism such as the steam engine, for example, are less in proportion as the pressure of the aeriform medium (the steam) is greater, and the speed at which the mechanism is worked is greater; it would therefore be reasonable to expect, on account of the extremely high value of the ether pressure and the high velocity with which the molecular mechanism for deriving motion from the ether is worked, that the total dimensions of this mechanism to develop a given power would be exceptionally small.

If we imagine a portion or stick of coal about the size of an ordinary lead pencil to be ignited at one end so as to burn away at the moderate rate of twenty grains per minute, then this little piece of mechanism represented by the ignited end of the piece of coal would be developing one horse-power under the action of the ether. Here the pressure of the motive agent is so intense, and the parts of the mechanism are so beautifully balanced and curbed by the high elasticity of the ether, that the mechanism is enabled to work at a high speed, thereby developing an intense energy by small dimensions. If only this piece of molecular mechanism could be connected up or brought into perfect gear with mass mechanism, so that the motion was transferred from molecules to masses without loss, a valuable result would be attained. Thus in the transmission of motion between the molecular mechanism and the mass mechanism of the steam engine, a field for improvement evidently exists, in reducing the loss that at present occurs in the carrying over of the motion.

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SECTION XIX.

143. *The Interchange of Motion at the Discharge of a Gun.*—The physical process involved at the discharge of a gun presents some points worthy of notice, which we will here allude to. Considering the state of the case previous to the discharge, it is well, first, to have a clear conception of the fact of the ether pervading with the utmost facility the body of the cannon, the ether occupying the molecular interstices and surrounding the molecules of the metal, so that, therefore, the slightest difference of the ether pressure (due to any disturbing cause) would immediately readjust itself across the body of the gun. It may perhaps facilitate the conception of this, if the known fact be kept in view that even the gross molecules of matter (such as the molecules of hydrogen gas) will permeate and pass through iron at a moderate temperature; and the dense metal, gold, is permeable by water under pressure. So that in addition to the molecular interstices which the ether pervades freely, the metal must also be porous.

We observe, therefore, before the discharge, the ether enclosing its intense store of motion pervading the body of the cannon, and inserting itself between every molecule of gunpowder, ready to part with a portion of its motion at any instant. The molecules of gunpowder are also in an intense state of vibration, due to the high absolute temperature existing (normal temperature). We note, therefore, an ingeniously disposed and delicately poised train of matter, at present in a state of dynamic equilibrium, the whole pervaded by a physical agent of exhaustless energy, from which it is only necessary to divert a small portion in order to cause the propulsion of the shot. The blow struck upon the percussion cap, by urging a few of the vibrating molecules into proper proximity, is sufficient to upset this equilibrium of motion, and brings the ether into action, the motion passing from the ether through the train of matter to the shot, and thence to the ether (in the waves emitted by the incandescent gases, the work of the shot, &c.), in a cyclical process. As regards the mode in which the process effects itself, the same considerations apply as in the case already considered of the explosion of the mixed gases, oxygen and hydrogen.

During the time of the explosion the ether particles in the bore of the gun lose a certain fraction of their normal velocity by transference to the molecules of gunpowder, which loss of motion, if it continued without renewal, would conduce to a reduction of the ether pressure in the interior of the gun; so that the inference is necessary that on the instant of the disturbance of the equilibrium of the ether pressure by the motion transferred to the first few molecules of gunpowder, a readjustment of pressure com-

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mences to take place across the body of the gun in the form of a wave, the free communication existing with the external ether rendering it impossible for any appreciable difference of pressure to accumulate; and, therefore, during the whole time of the explosion a continuous wave, representing a succession of small decrements of velocity sustained by the ether particles (the decrements being very small compared with the normal velocity of the particles), must pass through the gun, the energy of the ether within the gun being in this way sustained continuously during the explosion; and on account of the high speed of the particles the loss of motion is, during the comparatively slow process of the explosion, spread over a vast radial volume of the ether, whereby local disturbance of the equilibrium of the ether is prevented. The spherical wave expands as it recedes, distributing the loss of motion at last over so vast a number of particles, that the loss of motion, although existing as a whole, soon practically ceases to exist as far as each particle taken by itself is concerned. It forms a point of mechanical interest to note the process by which this motion is renewed, and the lost motion got rid of, transmitted to a distance, and dissipated by subdivision; also to note the neat way in which the two mechanical conditions fit into each other, viz. the high speed of the particles of the agent being the only condition on which the agent can effect an intense development of work, and at the same time this is the very condition on which alone the renewal of transferred motion can take place with adequate speed.

144. The interchange of motion in such a case as this, and, indeed, in the general phenomena of the interchange of motion between the ether and the molecules of matter, might properly be regarded as constituting a "focus of energy." When, for example, in the present case, the process of the explosion has attained its maximum, we have a focus of energy, represented by the projected shot and products of combustion, or we have motion withdrawn from all sides radially and concentrated at a focus, the loss of motion by the ether diminishing as the square of the distance from the focal point. Conversely, when the projected products of combustion at first vibrating up to incandescence, suddenly lose their motion by retransference to the ether, we have a loss of motion by matter at a focal point, and an equivalent gain of motion by the ether, the gain diminishing radially from the focal point; the collective sum of motion having remained *constant* at every instant, before, during, and after the explosion. The gain of motion at the focus being concentrated at a point of space, is extremely intense; and since this motion is that of visible masses, and of palpable clouds of expanding vapour, this gain of motion naturally appeals directly to the senses. The equivalent loss of motion by the ether being subdivided or distributed over a vast radial volume of the ether, and this loss representing but a very

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small part of the normal velocity of the particles, this loss of motion naturally cannot appeal directly to the senses; indeed, if the loss of motion could make itself directly palpable to the senses, then the agent would be incompetent to perform its work properly.

145. If the effect of the explosion of gunpowder be considered, then it may be said that, as a mechanical means to an end, the action of the ether is the only conceivable process by which the result could be attained, for the object is to impart suddenly to small masses of matter (the molecules of gunpowder) a rapid motion, for the production of a forcible mechanical effect. Now, to impart this rapid motion there must exist a still more rapid motion at disposal, or, in other words, the component particles of the motive agent must have a higher velocity than that intended to be developed, for in order for the particles of the agent to sustain their action against the small masses (molecules), these particles must at least have such a velocity as to enable them to follow up with facility the movements of the small masses. Thus, for instance, in a precisely analogous way, the motion of the molecules of gunpowder must be more rapid than the motion of the shot, or these molecules would be wholly incapable of sustaining their action against the rapidly advancing shot. So in the same way the motion of the ether particles must be more rapid than that of the molecules of gunpowder, or these particles would be wholly unable to sustain their action against the molecules. The molecules of gunpowder merely serve as the convenient mechanism to transmit the motion of the ether to the shot, for the gunpowder, like the shot, has no motion of its own, and, therefore, must have the motion imparted to it. The ether, on the other hand, does not require to have motion imparted to it, since it *already has* motion. The ether is, therefore, the only competent *source* of motion; or the ether transfers motion which it already has through the gunpowder to the shot, the sum of motion thereby remaining constant.

146. We have now to consider a few points as regards the mode of action of the process. Here again the influence of vibrating energy upon the positions of equilibrium of molecules, as illustrated by the expansion and eventual dissociation of matter by heat, has an important part to play. The explosion of gunpowder being simply a case of rapid combustion, precisely the same considerations apply here with reference to the gradual approach of the components of the compound molecules after combination, subject to the utilization of the heat, as was treated of in the case of combustion; and with the additional important practical point here, viz. that the pressure against the shot is thereby greatly equalized and the initial strain moderated, or the advance of the shot along the bore of the gun brings the ether into fresh action.

In order to follow the steps of the process we must consider certain points. The first act of the ether is to generate the

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translatory motion of approach of the molecules in the process of combination. Those molecules which approach each other in the process of combination to form compound molecules, we shall term "components." Secondly, this translatory motion of approach of the components is resolved into a vibratory motion of the components, due to these components in their mutual approach being driven against the intercepted oscillating ether column in synchronous vibration. The compound molecules immediately after combination are therefore vibrating powerfully. This sudden development of vibrating energy has, by the stationary vibrations suddenly set up in the intervening ether, the effect of driving apart in all directions the compound molecules which, after combination, happen to be in the vicinity of others, a general translatory motion of compound molecules (the motion of gaseous matter) being thus set up, by which the molecules are driven in all directions with great force against the shot.

147. When two molecules are forcibly urged towards each other, whereby the molecules are driven against the intercepted oscillating ether column, the *accession* of vibrating energy thus produced acts as a resistance tending to check the approach of the molecules, or this accession of vibrating energy tends to urge the molecules farther apart; so therefore, conversely, an accession of vibrating energy artificially produced (as by heat) will urge the molecules farther apart. Thus the vibrating energy (heat) produced at the approach of molecules in the act of combination tends to urge the molecules farther apart, and the effect, therefore, is that the molecules do not approach into such close proximity as they would do if this accession of vibrating energy were not developed; and as this vibrating energy (heat) is subsequently expended, the molecules gradually approach into closer proximity. Since, therefore, an accession of vibrating energy urges molecules apart, i. e. produces a translatory motion of the molecules from each other, *vibratory motion is thereby convertible into translatory motion;* and since, conversely, a translatory motion of two molecules towards each other is followed by an accession of their vibratory motion, *translatory motion is thereby convertible into vibratory motion.*

148. The mutual convertibility of these two fundamental forms of motion admits of further illustration if we take the case of a metallic bar; when by producing a motion of translation of the molecules of the bar towards each other (by compressing the bar), this translatory motion is converted into vibratory motion (heat); and, conversely, when the vibratory motion of the molecules of the bar is artificially increased (as by heating the bar), this vibratory motion is converted into translatory motion, or the molecules are caused to recede (as observed in the expansion of the bar).

So in the case of the action of the gunpowder under consideration, the sudden development of vibratory motion in the compound molecules after combination, causes these molecules to recede or

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rebound from each other in all directions, vibratory motion being thereby converted into translatory motion; or the vibrating energy of the ether column intercepted between each pair of receding molecules is reduced by an amount representing the translatory motion imparted to the molecules, and thus the molecules are chilled at their recession.

149. *Translatory motion and vibratory motion are therefore mutually convertible, or the one will produce the other.* These constitute the two fundamental and interconvertible forms of motion, by the permutations of which all the varied molecular effects are produced. The mutual convertibility and dependence of these two fundamental forms of motion constitute, therefore, an important practical principle in connection with the working of physical phenomena.

150. Thus, in the physical process involved in the case of gunpowder, *translatory motion is first converted into vibratory motion,* as illustrated by the development of vibratory motion (heat), due to the translatory motion of approach of the components of the molecules under the action of the ether; and then this *vibratory motion is reconverted into translatory motion,* as illustrated by the sudden rebound of the intensely vibrating compound molecules after combination. The principle involved in the process of the explosion is therefore simply that translatory motion is converted into vibratory motion, and then reconverted into translatory motion. These form the necessary mechanical steps of the simplest conceivable character, by which the translatory motion of approach of the components of the molecules under the action of the ether is finally resolved into a form of motion capable of acting against the shot.

151. As regards the order of the steps of the physical process, the mode of action in the case of gunpowder may serve as a type of explosives, and of all cases of combustion and of chemical reactions generally; or in all cases translatory motion is converted into vibratory motion, and then reconverted into translatory motion; or to particularize more exactly, the translatory motion of approach of the components to form compound molecules is converted into a vibratory motion of these components, and this vibratory motion of the components is finally converted into a translatory motion of compound molecules.

In some cases of extremely feeble reactions the vibratory motion (heat) developed may not be sufficient to cause an actual rebound of compound molecules in the form of vapour, but the compound molecules may simply recede from each other a short distance in translatory motion without actually separating. The amalgamation of zinc may serve as an illustration of such a feeble chemical process. Here, after translatory motion has been converted into vibratory motion (heat) at the approach of the component molecules of mercury and zinc to form compound molecules, these compound molecules merely recede a short

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distance from each other by the conversion of vibratory motion into translatory motion (as illustrated by the slight expansion of the zinc from the heat developed); but the vibratory motion is here not intense enough to cause a rebound of the compound molecules in the form of vapour. In the case of the approach of the molecules of oxygen by the combustion of a piece of magnesium wire, on the other hand, the vibratory motion developed is such that by its conversion into translatory motion the compound molecules of the solid magnesia are driven from each other in the vaporous form.

152. Translatory motion and vibratory motion, therefore, being *interconvertible*, these two forms of motion have necessarily an intimate dependence upon each other, the slightest increase or diminution of the one being followed by a corresponding increase or diminution of the other. Thus, for example, in the illustrative case of the gunpowder, as the translatory motion of the compound molecules is being expended by transference to the shot, vibratory motion (heat) is being continually converted into fresh translatory motion, or the translatory motion of the compound molecules is sustained at the expense of their vibratory motion; and this vibratory motion is itself again sustained at the expense of the translatory motion of approach of the components of the compound molecules under the action of the ether, these components being slowly and forcibly urged into closer proximity by the ether as the shot advances, thereby developing fresh vibratory motion, and, by its conversion into translatory motion, giving a fresh impulse to the shot. The advance of the shot along the bore of the gun, therefore, brings the ether into fresh action, or the demand for energy causes a fresh supply.

153. As an analogous example of the *interconvertibility and mutual dependence* of translatory motion and vibratory motion, we may take the known fact that, in the case of gases, temperature and pressure are mutually dependent. The temperature (heat of the gas), however, consists in the vibratory motion of the molecules which give rise to the observed rapid and periodic ether waves of heat, the pressure of the gas being produced by the translatory motion of the molecules; and any disturbance or variation of one of these forms of motion is attended by a variation of the other, or the equilibrium of motion readjusts itself by conversion of the one form of motion into the other. Thus, if an impulse be given to the translatory motion of the rebounding molecules of a gas by suddenly compressing it, then the equilibrium of motion readjusts itself by the conversion of the excess of translatory motion into vibratory motion (heat), as indicated by the rise of temperature; and, conversely, if the vibratory motion be artificially increased (as by exposing the gas to a source of heat waves), then the excess of vibratory motion is converted into translatory motion, as indicated by the rise of pressure. The increase in the velocity of translatory motion attendant on the increase of the

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vibratory motion in heating a gas is also illustrated by the increased velocity with which the molecules of a heated gas in their mutual interchange of motion transmit any impulse (such as a wave of sound).

The interchange of motion between two gaseous molecules forms an illustration of the permutations of translatory motion and vibratory motion. Thus, at the approach of the two molecules, each comes to the end of its path previous to rebounding, by converting its translatory motion into vibratory motion (heat), and, conversely, the rebound takes place by the conversion of vibratory motion into translatory motion. The interchange of motion between a group of molecules forms a perfectly analogous case. Thus, at the interchange of motion between two billiard-balls, for example, each ball comes to rest for an instant (previous to rebounding) by converting its translatory motion into vibratory motion (heat); and at the rebound vibratory motion is, conversely, converted into translatory motion.

154. The general phenomena of evaporation constitute another example of the interconvertibility of these two fundamental forms of motion. Thus, to take the important practical case of the generation of steam, for instance. Here, by the transmission of vibratory motion from the molecules of fuel to the molecules of water, the rebound of these water molecules in free translatory motion (in the form of steam), takes place by the conversion of their vibratory motion (heat) into translatory motion.

An endless variety of examples might be referred to, as illustrative of the important part these two fundamental forms of motion have to play in the working of physical phenomena; indeed, from the very fact that all molecules on the earth's surface possess an extreme intensity of vibratory motion, and since translatory motion constitutes the one conceivable permutation of which vibratory motion admits, and since also all physical processes in their fundamental working depend on translatory movements of approach and recession, in which these two forms of motion are directly concerned, there is, therefore, perhaps scarcely a movement of matter in which the interconvertibility of these two fundamental forms of motion has not a part to play.

SECTION XX.

155. The mode in which the supply of energy by the ether is influenced by the demand constitutes a noteworthy point; and to illustrate this somewhat further, we may trace the steps of the process backwards in the previous illustrative case of the gunpowder, this serving as a type of molecular actions. If we regard the gaseous molecules impinging against the advancing shot within the bore of the gun, and selecting any one molecule, then this

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molecule, in being driven against the shot, must have rebounded from some other molecule in the rear. The intercepted pulsating ether column, therefore, which caused the mutual rebound of the two molecules (thereby propelling the molecule against the shot), accordingly lost by transference an amount of vibrating energy equivalent to the work done; or, in other words, at the rebound of the two gaseous molecules, both the intercepted ether column and the molecules themselves lost vibratory motion by its conversion into translatory motion. This loss of vibratory motion by each compound gaseous molecule, however, disturbs the equilibrium of the ether pressure between its vibrating components. The ether accordingly comes into action, readjusting the equilibrium of pressure by urging the components into closer proximity, thereby developing fresh vibrating energy, and by its conversion into translatory motion giving a fresh impulse to the shot; and thus the advance of the shot along the bore of the gun by this special physical process brings the ether into fresh action, or the demand for energy entailed by the advance of the shot causes a fresh supply. It forms a beautiful mechanical process to contemplate the expanding gas as the shot advances, followed by the closer approach of the components of the compound molecules under the action of the intense ether pressure, the attendant partial renewal of vibrating energy, and its instant conversion into translatory motion, whereby the action directed against the shot is renewed, the ether following up the effort in a beautiful manner, and adjusting the supply of energy in accordance with the requirements of the work. By this special physical process, therefore, not only is the initial production of heat moderated, and the development of heat equalized by being spread over a certain interval of time; but what is more important, the initial strain upon the gun is moderated, and instead of the intense initial heat and strain that would result were all the energy expended by the ether concentrated in the first instant of the explosion, the energy of the ether is held to a certain extent in reserve, and part is given off after the shot has had time to get in motion, the strain against the gun being thus equalized, and the effort directed against the shot thereby finely graduated by being spread over a certain interval of time.

156. If we imagine a case where gunpowder is exploded in a perfectly closed vessel, strong enough to bear the pressure without yielding, then here no means whatever are given for the performance of work beyond the slow communication of vibratory motion (heat) to the molecules forming the sides of the vessel, so that, therefore, the action of the ether would be checked, or its energy would be held in reserve. The components in the process of combination would be merely driven in a short distance towards each other, their farther approach being checked by the absence of means for utilizing their vibratory motion. If we imagine the

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vessel to burst while this high temperature still exists, then the sudden facility thus given for the performance of work would bring the ether into fresh action; for vibratory motion being then rapidly converted into translatory motion in the free expansion of the gas, the ether would therefore soon urge the components of the compound molecules into their final positions of proximity. If we suppose the vessel to hold until the enclosed gas assumes the normal temperature, then the slow communication of vibratory motion to the molecules forming the sides of the vessel would keep the ether in action during the whole time of the cooling down, the components of the compound molecules being slowly and forcibly urged into closer proximity as their vibratory motion is given off; fresh increments of vibratory motion and fresh increments of translatory motion being thus continually developed as the cooling down proceeds. The result would, therefore, be that the temperature of the enclosed gas would fall more slowly than if the above action did not take place.

157. Conversely, when gunpowder is exploded in a perfectly unconfined state, the work of the ether is done much quicker or in less time, for here means are given for the performance of work in the expansion of the gas, and vibratory motion being thereby rapidly converted into translatory motion; the ether accordingly rapidly follows up the demand for energy by urging the components of the compound molecules into closer proximity, these components soon approaching into their final positions of equilibrium due to normal vibrating energy, where the work of the ether ceases.

SECTION XXI.

158. *The Physical Conditions which determine Combustion.*—In proceeding to consider briefly the physical conditions upon which the development of the phenomena of combustion, &c., depends, we may note, first, the fact previously referred to, that heat (i. e. an elevation of temperature above the normal) is in general unfavourable to a stable state of chemical union; or heat, as a general rule, tends to separate chemically combined molecules, and indeed at a certain elevation of temperature (temperature of dissociation) chemical combination is entirely prevented. Heat, therefore, can by no means be said to be in itself the essential condition to develop combustion.

The condition required to produce combustion may be simply stated to be, that the molecules concerned should be brought into a certain degree of proximity; to effect which result a certain amount of force is in general required.

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Now, in most cases the most convenient way of bringing the molecules concerned into the requisite proximity is by producing a forcible molecular disturbance by some cause for which heat (i.e. matter in intense molecular vibration) is well adapted; so that this may serve to explain why in most cases in practice heat is applied in the first instance to develop combustion, and after combustion has once been developed, the continuous molecular disturbance thus kept up, by continually urging additional molecules into the requisite proximity, has the effect of maintaining combustion, so that combustion becomes, as it were, a self-acting process.

159. Thus, for example, when a jet of gas is turned on, the molecules of air and gas are interchanging motion among each other in the free translatory motion characteristic of the gaseous state; but this normal rate of translatory motion is not sufficient to carry the molecules over the outer neutral point in their mutual interchange of motion. By the application of a flame (vibrating matter), vibratory motion is imparted to the molecules of air and gas, and this vibratory motion being converted into translatory motion, combustion accordingly sets in as soon as the molecules have by increase of their translatory motion acquired a sufficient momentum to carry them over the outer neutral point in their mutual interchange of motion; and after combustion has once set in, the flame, by continually developing translatory motion in the adjacent molecules of air and gas, thereby serves the purpose of giving that small initial impulse which is requisite to bring the ether into action in chemical combination. The special action of heat in developing and maintaining combustion would therefore simply consist in giving such a degree of translatory motion to the molecules concerned that they are carried over the neutral point in their mutual interchange of motion.

By the combustion of a solid body, the same considerations would hold as in the case of a gas, in so far as it is known that in the case of a solid body in the process of combustion, the molecules of the solid are in great part carried up in the form of vapour before combustion ensues; although the inference is necessary that combustion might go on at the surface of a solid, provided the translatory motion of the impinging air molecules was augmented to a sufficient degree by the presence of the flame.

160. If by any means two molecules could be brought up to the outer neutral point (i.e. that point where the ether in the process of combination first comes into action) slowly, so that the vibrating energy generated in reaching this point had time to dissipate itself, so that, therefore, the two molecules arrived at the outer neutral point still at normal temperature, then this physical condition would be eminently favourable to the energetic combination of the molecules, the ether coming into action with

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augmented energy, owing to the absence of a previous abnormal increase in the vibrating energy of the molecules.

We do not mean to assume that the quantity of heat generated at the combination of molecules at normal temperatures is greater than the quantity generated at the combination of the molecules after having been previously heated, for the process of combination in the case of heated molecules is necessarily spread over a longer period of time, so that the total quantity of heat generated may well be appreciably the same as in the case of molecules at normal temperature whose combination takes place with greater energy and lasts a less time. In the case of molecules at normal temperature, the velocity of translation generated by the ether is necessarily greater, or the ether comes into action with greater energy, the molecules, therefore, being in the first instance driven in nearer to each other than in the case of molecules previously heated; but in both cases, i. e. whether the molecules have been previously heated or not, the final positions of equilibrium taken up by the molecules are the same as regards relative distance, when the temperature, after combination, has fallen to the normal, the relative distance of the molecules being determined solely by vibrating energy.

The physical means of bringing molecules thus into the requisite proximity for combination (combustion) to ensue, without previously heating the molecules, would evidently be the application of an intense but gradually applied pressure to the molecules concerned.

161. However, we may observe that in that case, where either one or both of the reagents employed are a gas, certain considerations would indicate that it would be impossible to produce combustion without initial heat, and this would therefore apply to the general cases of combustion, where the atmosphere is one of the reagents. This would follow from the consideration that the molecules of a gas are in free translatory motion, and are therefore quite beyond control, so that the application of a pressure would be of no avail in this case; for evidently the only possible means of causing a gaseous molecule in free translatory motion to approach nearer to the combustible from which it rebounds, is by augmenting the translatory motion of the molecule. The degree of proximity into which a gaseous molecule approaches to the surface molecules of the combustible by whose vibrations set up in the ether the approach of the gaseous molecule is at first checked, will clearly depend on the velocity of translatory motion of the molecule, and it therefore follows that since the molecule is beyond control, the only possible means to make it approach into sufficient proximity for combustion to ensue is by augmenting the velocity of approach of the molecule, whereby its momentum may be sufficient to carry it over the outer neutral point. Since, however, it is a physical impossibility to change the rate of trans-

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latory motion of a gaseous molecule without heating it, or an impulse cannot be given to the molecule without increasing its vibratory motion, it follows, therefore, that combustion cannot be developed, when a gas is one of the reagents employed, without initial heat. Thus, it would probably be impossible to explode a mixture of oxygen and hydrogen gases by a gradually applied pressure, however intense, at least so long as the gaseous state was retained; for the increase of pressure (slowly applied) would only have the effect of bringing a greater number of molecules into the unit volume of space, or of reducing the mean length of path of the molecules; but so long as the temperature, and therefore the rate of translatory motion of the molecules, remained constant, the molecules in their mutual exchange of motion would not approach into greater proximity than if the pressure had not been applied; so that the inference follows that so long as the gaseous state is retained, no amount of pressure would develop combustion. This consideration applied to the atmosphere (matter in the gaseous state), the principal reagent in combustion, would indicate the existence of a special condition for safety.

On the other hand, in that case where both the reagents are in the solid state, and therefore the molecules are completely under control, having stable positions of equilibrium, then there is no reason to doubt that combustion might be produced by the application of a pressure sufficiently intense to bring the molecules into the requisite proximity. Thus, probably percussion powder might be exploded by a gradually applied but intense pressure, and the inference appears warranted that the explosion in such a case would be exceptionally violent, since all the molecules of the mass would be brought at about the same time into proper proximity, resulting in the simultaneous combination of the entire mass, the ether also coming into action with augmented energy, due to the favourable temperature of the molecules, or the absence of a previous abnormal increase of their vibrating energy.

162. Regarding the immunity of gases from combustion by pressure, or the impossibility of combustion being developed by pressure alone when one or both the reagents are a gas, there are certain possible exceptional conditions which we may here notice as possibly having a practical interest. It is a known fact that the molecules of gases adhere to the surface of solids in the form of a thin film, the gaseous molecules in this condition being fixed as if they were the molecules of a solid body. Hence, in this case, if the substance were combustible, the deduction is warranted that a combination of the molecules might be effected by a gradual and sufficiently intense pressure applied to the molecules of the film, the gaseous molecules in this case being quite under control, or they may be readily pressed against the com-

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bustible to which they adhere. Porous bodies, which expose a large surface to the atmosphere, stored in considerable quantities so as to be under pressure, would be the physical conditions most favourable to produce the above result. We cannot avoid the conclusion that the phenomena popularly termed phenomena of "spontaneous combustion" are simply physical examples of combustion by pressure under these conditions. To select a well-known example, if we take the case of a stack of hay; then this material is full of pores, which are penetrated by the air, a film of air adhering to the interior of each pore, the whole forming a very extensive area: the molecules composing the film having lost their free translatory motion resemble the molecules of a solid body. The only condition required, therefore, would be a sufficient pressure to urge a few of these molecules of air into such proximity with the combustible material (carbon molecules, &c.) of the stack, that the neutral point is reached when the ether coming into action, the stack might thus be set on fire or charred in places, as in accordance with observation, assuming that the weight of the superincumbent material was sufficient to satisfy the condition for pressure. In an analogous manner, the development of combustion in coal, when stored in considerable quantities so as to be under pressure (and possibly partly in a finely-divided state), may afford another example of combustion due to the above physical causes. The occurrence of a like effect in the case of stored oiled cotton and other substances distinguished for their porosity, may be cited as possibly constituting other examples of the development of combustion under the above special physical conditions.

SECTION XXII.

163. *Absolute Quantity of Energy in the Unit Volume of Space.*—We shall now consider more particularly the energy enclosed by the ether, with the endeavour to give some idea of the absolute value of the energy represented by the motion of the ether particles contained within a given portion of space, with the object, if possible, to fix upon a limiting value for this energy, or the lowest value consistent with what physical facts would require.

The conditions required in order to determine the amount of energy enclosed in the unit volume of space are clearly, first, a knowledge of the quantity of matter in the form of ether contained in the unit volume of space (i. e. the density of the ether); and secondly, the normal velocity of the ether particles. Now, although we do not know the density of the ether independently, nevertheless since density is determined by pressure and velocity

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of component particles, if, therefore, by a known limiting value for the velocity of the ether particles, a limiting value for the ether pressure can also be fixed upon, then a limiting value for the ether density is thereby given. The limiting value for the velocity of the ether particles is given by the measured velocity of a wave of light. As regards the value for pressure, we take the estimate already fixed upon: that this amounts to 500 tons per square inch as the lowest limiting value. There are valid grounds for inferring that this value for pressure has been under-estimated; for we assumed the total ether pressure as a small multiple of the observed difference of pressure in the case of "cohesion," whereas, as before remarked, it is a known fact that the force required to separate chemically combined molecules must be many times greater, this indicating the high intensity of the controlling ether pressure, and showing that an estimate of this pressure from the case of "cohesion" must be but an inadequate representation of the reality. The tremendous energy developed in explosives, which is the very energy of the ether itself, is a direct indication of the intensity of the ether pressure, which is the necessary accompaniment of this energy.

That this value for pressure has been under-estimated, a bare consideration of the dependent value for density would almost show, for the ether density corresponding to this pressure ($\frac{1}{5264800}$ of the atmospheric density) represents a density so insignificant as to be less than that of the best gaseous vacua.

164. The actual density of the ether might, therefore, well be greater than the above estimate. A greater density would, of course, involve a proportionally greater pressure. It is, however, well to keep in view that there is not the slightest mechanical impediment to the existence of an extremely intense pressure, for so long as the pressure about a molecule of matter is under normal conditions perfectly balanced, it can be of no special import what its value is. If, for example, it were an essential condition to a steady and perfectly balanced pressure that the density of the ether, i. e. the quantity of matter relatively to the volume of space, should be infinitesimal, then the observed steadiness of the stable aggregation of molecules determined by the ether pressure would warrant the inference that such was the fact. But the actual physical conditions are quite otherwise; for an addition to the quantity of matter contained in the unit volume of space, or an addition to the number of ether particles, so far from rendering the pressure due to the motion of these particles less steady, would only render it more steady; and thus, although by this increase in the number of particles (increase of density) the pressure might be greatly increased, the concealment of the existence of the pressure from the senses would, on account of the perfection of the equilibrium, be if possible more effectual; and although the value of the energy enclosed might thus be greatly

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augmented, the reduced length of path of the particles would only serve to remove the motion still farther beyond the reach of detection by the senses. Hence we may observe the perfect mechanical possibility of the existence of an ether density very much greater than the above estimate. We will, however, take the above estimate for the ether density as a basis for deducing the value of the enclosed energy, it being only our object to arrive at a limiting value for this energy, having therefore valid grounds for concluding that the results arrived at for the value of this energy will be less than the facts as they actually exist.

165. To give an idea, first, of the enormous intensity of the store of energy attainable by means of that extensive state of subdivision of matter which renders a high normal speed practicable, it may be computed that a quantity of matter representing a total mass of only one grain, and possessing the normal velocity of the ether particles (that of a wave of light), encloses a store of energy represented by upwards of one thousand millions of foot-tons, or the mass of one single grain contains an energy not less than that possessed by a mass of forty thousand tons, moving at the speed of a cannon ball (1200 feet per second); or otherwise, a quantity of matter representing a mass of one grain endued with the velocity of the ether particles, encloses an amount of energy which, if entirely utilized, would be competent to project a weight of one hundred thousand tons to a height of nearly two miles (1·9 miles).

This remarkable result may serve to illustrate well the intense mechanical effect derivable from small quantities of matter possessing a high normal velocity, the extremely high value of the effect depending on the fact that energy rises in the rapid ratio of the square of the speed.

166. A cubic foot of air weighs 56·5 grains, so that with the above limiting value for the ether density ($\frac{1}{5264800}$ that of air), a quantity of ether representing the total mass of one grain would be contained in a cubical portion of space with side of cube equal to about forty-five feet. Hence a portion of space of these moderate limits contains, in the energy of the concealed motion of the enclosed ether, not less than the above prodigious work-producing power.

167. With the above limiting values for normal velocity of particles and density, we may give a few more numerical results illustrative of the energy enclosed by this great physical agent. The energy in the form of concealed motion contained in one cubic foot of space amounts in units of work to not less than ten thousand seven hundred foot-tons. This is the energy which a projectile of one quarter of a ton would possess when moving at the rate of 1600 feet per second. Since this velocity happens to be that of the molecules of air in their translatory motion at normal temperature, it may be of interest to note that the energy

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enclosed by a cubic foot of ether represents the energy of translatory motion of the molecules (not taking into account the vibrations of the molecules) of a quarter of a ton of air. This amount of air would occupy a cubical space with side of cube equal to about forty-one feet, and the energy of the translatory motion of the molecules of this mass of air would be competent to project it to a height of about seven miles.

168. That which appeals most directly to the senses as energy, and which our ideas naturally connect with the visible motions of large masses of matter, is but insignificant when compared with the energy of the concealed motions of molecules, and is as nothing when compared with the intensity of the energy enclosed by the ether in the motion of its particles.

It is our object to consider this question in all its points, for we do not content ourselves merely with putting forward the bare deduction, to which we have been necessarily led, that this energy exists; but it is our endeavour rather to show the consistency of the fact; or we examine all the points of the physical problem with the view to show that the existence of this intense energy on all sides as a physical fact admits of being brought into harmony with just mechanical principles, and of being practically realized and appreciated.

On the first consideration of the subject there may undoubtedly be a difficulty in forming a satisfactory conception of the existence of an agent enclosing such an intensity of energy as this; indeed, at the first thought there may even appear something wild in the idea of the continued presence of an agent competent to transfer motion to explosives; indeed, one would perhaps naturally ask, How can such an intensity of energy exist without making itself directly palpable to the senses in the normal state of the ether? The answer to this is, that it is theoretically deducible beforehand that the existence of such an intense store of energy is perfectly consistent with its concealment from the senses; indeed, that so far from concealment being inconsistent with its existence, it may be shown (on grounds already pointed out) that concealment is absolutely essential to its existence; in fact, that without considering the question as to its existence at all, it is theoretically deducible beforehand as an independent deduction that if such an intense store of motion did exist, then it would *necessarily* be *concealed;* and further, that the existence of a store of *motion* of a high intensity is the *necessary* consequence of the known *impalpable* quality of the ether; the agent becoming less and less palpable to the senses as the rapidity of the motion of its component particles increases; and therefore the less palpable the agent, or the more effectual the concealment of the motion from the senses, the higher would one be warranted, on theoretic grounds, in assuming the intensity of the enclosed store of energy to be.

169. It is well to keep the above considerations in view, since

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there is an undoubted tendency to ignore the existence of anything which does not appeal directly to the senses. If such a course were followed, however, a vast number of important physical facts would pass unknown, and work their influences unheeded, for the most important facts may not always lie on the surface. Thus, if we take the important phenomena of Heat, for example. The motion termed "Heat" is, under normal conditions, completely concealed, and how intense (as expressed in mechanical units) is the energy of the molecular motion of substances at normal temperature, this energy greatly surpassing the energy of the movements of large masses which appeal to the senses. If, therefore, the existence of this concealed energy be admitted and realized, then there can be no real difficulty in appreciating and harmonizing with just mechanical principles the enclosed energy of the ether; for if the gross molecules of matter attain such an intensity of motion as the mechanical equivalent of heat proves, then how much more may the minute component particles of the ether, whose motion is entirely unobstructed, attain a high normal speed? And when the existence of the rapid motion is once appreciated, then the existence of the intense store of energy follows as an absolutely necessary consequence.

170. The normal speed as deduced for an ether particle may naturally appear inordinately high, according to our general ideas of speed, which attach themselves to the motions of visible masses; but it is well to note that these motions of visible masses take place under physical conditions which are eminently unfavourable to the development of high speeds, whereas the concealed motions of molecules and particles take place under conditions eminently favourable to high speeds, so that the two cases are not fairly comparable.

Thus the movements of visible masses of matter near the earth's surface, where the motions come under the observation, cannot take place without continual and forcible obstruction by other matter (the air, &c.), so that the attainable speeds are very limited in such a case, and yet this is precisely the case from which our general ideas of speed and energy are formed. The motion of the molecule of matter, on the other hand, can take place with comparative freedom, the ether being the only obstruction, and the resistance thus offered is but small. Hence we may observe that the motions of molecules take place with some rapidity, as illustrated, for example, by the rapid translatory motion of the molecules of gases, which by their interchange of motion can propagate waves at a considerable speed.

The motion of the ether particle, on the other hand, takes place under the most favourable conditions conceivable, for there is nothing whatever to obstruct or curb its free motion. Hence the possession of a high speed by the ether particles can be said to

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be only consistent with the special physical conditions of the case. Even large visible masses of matter may attain high speeds when the physical conditions are favourable. Thus, in the free ether, masses of matter are known to attain speeds by which many miles are traversed even in a second of time, and quantities of matter in the form of comets are actually observed to be propelled round the sun at a speed of upwards of 300 miles per second. If, therefore, it be realized that large masses of matter, whose motion must be obstructed to a certain extent by the presence of the ether, attain speeds represented by hundreds of miles per second, what difficulty can there be in realizing the existence of a high speed in the case of the minute ether particle, which moves entirely without obstruction, and whose minute mass renders perfectly practicable a high speed without producing physical disturbance of the equilibrium of the molecules of matter which the ether surrounds?

Moreover, when it is considered that this motion of the ether particles constitutes the sole physical means whereby motion can be transmitted across the vast intervening distances of stellar space, and that even as the fact stands this transmission of motion by interchange of motion among the ether particles requires upwards of three years to traverse the intervening ether which separates the nearest star; then the above value for the normal velocity of the ether particles is surely no more than consistent with the special functions which belong to this great physical agent.

If, then, the above value for the normal velocity of the ether particles be realized as a reasonable and consistent fact, then the existence of the intense store of energy—of the value of which we have endeavoured to give some idea by a comparison with the greatest observed cases of energy which appeal to the senses—follows as a necessary consequence, as certain as the mathematical fact that energy rises as the square of the speed.

We may just add here that a consideration of the physical conditions involved in the case given of a comet, may serve as another illustration of the mechanical fitness of the high normal velocity possessed by the ether particles, these particles having such a suitable speed that they are not only able to follow up the matter forming the comet (travelling at 300 miles per second) with facility, but are capable of transmitting motion to it, i. e. of propelling the comet along its course.

171. Since the visible motions of large masses upon the earth's surface constitute the only means by which a distinct figure or illustration of energy can be presented to the mind, although energy in this form can never attain a high intensity, we will take a few more illustrative cases, as serving to exemplify the far higher intensity of the energy of *concealed motion.*

It is well to keep practically in view that if it were attempted

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beforehand to devise what physical conditions should be satisfied to render possible the existence of a store of energy of the highest possible intensity, capable of producing dynamic effects of the most forcible character, then the conditions satisfied in the physical constitution of the ether would be precisely those required. Hence, in dealing with the value of the energy enclosed by the ether, it is to be expected beforehand that the results arrived at will represent extremely high figures as expressed in mechanical units.

172. If we take the case of a railway train whose weight amounts to 200 tons, moving at the rate of 60 miles an hour, then the energy contained in the train is such, that if the motion of the train were supposed diverted vertically upwards at any instant, the train would project itself to a height of 121 feet; or the work-producing power of the train is therefore $121 \times 200 = 24{,}000$ foot-tons. This, however, would only represent the energy of the concealed motion of the ether contained in about $2\frac{1}{2}$ cubic feet of space.

If we suppose a collision of the train to take place, then the energy transferred to matter at the collision, the shock of which would be precisely equivalent to that produced by a fall of the train through 121 feet, would only represent the energy which $2\frac{1}{2}$ cubic feet of ether are competent to transfer to matter; or, in other words, the transference to matter of the concealed motion of the ether occupying a portion of space of these moderate limits would involve a dynamic effect greater than that developed at the collision of a train of 200 tons at the above speed, this point being illustrated by the destructive effects of the transferred motion of the ether in the case of "explosives," the dynamic effect of "lightning," &c.

173. To take a further illustration: if we imagine the ether occupying a cubic foot of space to be replaced by a cubic foot of lead, or the ether occupying any unit volume of space to be replaced by lead, then from the known density of the metal, lead, and from the known fact that energy is in the ratio of the density or mass, and as the square of the speed, it may be computed that for the energy contained in this unit volume of space to remain as before, it would be necessary for the mass of lead to have a translatory motion at the rate of 1470 feet per second (about the speed of a cannon ball); or, in other words, therefore, if space were filled with flying projectiles which graze each other in their close proximity, the energy thus existing would be scarcely competent to represent the energy of the concealed motion actually existing in the normal state of the ether.

The speed attainable by gross masses of matter, such as projectiles in the atmosphere, is necessarily extremely limited; yet because this is about the highest form of motion that appeals to the senses, the motion is naturally considered extremely rapid;

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yet it may be shown that the motion of a projectile vanishes when compared with the speed of the concealed motion of the ether particle. Taking the ordinary speed of a projectile, such as a rifle bullet, for example, at 1200 feet per second, then the speed of the ether particle (that of a wave of light) is to the speed of the bullet as 836,000 is to 1; or it may be computed that the speed of the ether particle bears the same proportion to that of the bullet, as the speed of the bullet bears to the rate of movement of the extremity of the large hand of a clock 10 inches in length. Since the motion of such a clock-hand is scarcely perceptible at a few feet distance, its rate of motion may be justly said to vanish compared with the speed of a bullet; in the same way, therefore, the motion of a bullet may be justly said to vanish when compared with the speed of an ether particle.

SECTION XXIII.

174. *Mass of the Ether.*—It is an unquestionable fact that the density of the ether, or the quantity (volume) of matter in the form of ether, relatively to the unit volume of space is very small; nevertheless, considering that the absolute quantity or total mass of the ether which occupies a spherical portion of space increases in the extremely rapid ratio of the cube of the radius, it is plain that the absolute or total mass of the ether may become very considerable, even when a moderate portion of space is considered.

Taking the above extremely low limit for the ether density ($\frac{1}{5264800}$ that of air), it may be computed that the quantity of matter in the form of ether enclosed within a cubical portion of space, with side of cube equal to about two miles (2·149 miles), would represent a total mass of one ton.

175. If we consider the ether contained within the bounds of the solar system, then it may be shown that by the above remarkably low density, the total quantity of matter in the form of ether enclosed within a radius extending to the limits of the solar system considerably exceeds the total quantity of matter represented by the entire mass of the sun, and that of all cosmical bodies within the system.

Taking the earth's mean density at 5·5 compared with that of water, the sun's mean density is represented by the number 1·364. The density of the air compared with water is known (weight of a cubic foot of air being 56·5 grains). Hence, taking the above value for ether density, given in terms of air, and expressing it in terms of the sun's density, we obtain the fraction $\frac{1}{55606000000}$. The sun's radius is known to amount to about four hundred and

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twenty-seven thousand miles; hence, if we take a radius from the sun's centre, whose length exceeds the radius of the sun in the same proportion as the cube root of the number of times the sun's density exceeds that of the ether, we obtain the radial limits in miles of a spherical portion of space, the total mass or quantity of matter in the form of ether enclosed within which equals the total mass of the sun; or we have $427,000 \times \sqrt[3]{55,606,000,000} =$ 1,629,800,000 miles.

176. Hence it would follow from this that with the above limiting value for the ether density, a radius lying somewhat within the orbit of Uranus (dist. of Uranus = 1,753,000,000 miles) encloses a quantity of matter in the form of ether, the total mass of which equals the total mass of the sun.

In the same way it may be computed that the total mass of the ether enclosed within the orbit of Neptune, representing the bounds of the solar system, exceeds by more than four times the total mass of the sun, together with the collective masses of the planetary members of the system.

In view of these considerations, it might truly be said that there exists more matter in what is not unfrequently looked upon as mere space, than the sum total of all that which is distinctively termed "matter" put together. So far from space being empty, space is so pervaded by matter, that the particles of matter, although extremely minute, are in incomparably closer proximity than the component molecules of solid masses.

177. As the total mass or quantity of matter in the form of ether enclosed within the limits of the solar system thus considerably exceeds the total collective masses of the sun and the planetary members of the system, and taking into account the intensity of the energy enclosed by the ether, it is plain that the total quantity of energy contained in the sun, represented by the heat there developed, must be but insignificant in comparison with the total energy in the form of concealed motion contained in that portion of the ether which is confined within the spherical limits of the solar system; for since a given quantity of ether encloses an amount of energy competent to impart to an equal quantity of matter the normal velocity of the ether particles, it would follow that a quantity of ether, representing only about one fourth of that which is contained within the limits of the solar system, would be competent, if its enclosed energy were entirely utilized, to impart to the entire mass of the sun the velocity of light.

178. If, therefore, when only the limited range of the solar system is regarded, the ether enclosed within these bounds represents a quantity of matter exceeding the total mass of the sun and that of the collective members of the system, and a quantity of energy far exceeding the total energy developed in the sun, what must be the fact if we regard the visible stellar

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universe, or that portion of the universe, of the scale and relative proportions of which a judgment can be formed, and of which our sun forms a component stellar member? Then, as a known fact, the amount of space occupied by the collective stellar members of this universe almost vanishes when compared with the amount of intervening space occupied by the ether, i. e. by the ether which is confined within the limits of this universe. The dimensions of the spherical portion of ether, enclosed within the radial limits of the solar system, would almost dwindle to a point when viewed from the nearest star.

The considerations applied to our own sun find equally their application in the case of other stellar suns; and thus a quantity of ether surrounding each stellar sun, the radial extent of which mass of ether almost vanishes when compared with the quantity of ether pervading the separating distance of this stellar sun from others, would represent a quantity of matter equal in mass to the stellar sun, and a quantity of energy, compared with which the total energy in the form of heat contained in the stellar sun is but insignificant in proportion.

In view of these considerations, one of the fundamental purposes of the intense store of energy enclosed by the ether becomes apparent, the vast total of energy developed in these stellar suns having been derived from the ether, as it is returned to the ether as these stellar suns pour their heat into space. When these points are taken into account, what would otherwise be the anomaly of the ether receiving all this energy and giving no return, or the anomaly of these myriads of stellar suns all pouring their stores of energy *unrequited* into space, finds its explanation; the process actually going on consisting in the return to the ether of the energy derived from the ether, the process consisting in the natural return of the energy to its original source, to be again available for useful ends.

SECTION XXIV.

179. There are certain known facts which would tend to the conclusion that the action of the ether in gravitation was the main physical cause concerned in the original development of the sun's heat. If we take the case of a quantity of matter converging towards a common centre at a high speed, under the feeble but long-continued propulsive action of the ether in "gravitation," then at the collision of this matter the stationary vibration of the intercepted ether would be necessarily largely intensified, due to the high speed of approach of the molecules; the latter, which are

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in synchronous vibration with the ether, thereby receiving a sudden large accession of vibrating energy (heat), and then rebounding in translatory motion.

If we single out any pair of the approaching molecules, then it may be observed, that however feeble the initial vibratory motion might be immediately previous to the collision, this vibratory motion would be at once reacted upon and raised to a high intensity, due to the rapid shortening and forcible compression of the oscillating ether column by the rapid approach of the two molecules against which the column abuts, the intense oscillations of the column then driving the molecules backwards with an energy which is the greater, the greater the rapidity of their approach, and vibratory motion is thus converted after the normal method into translatory motion. The component molecules of the entire mass of matter would thus, after the approach, rebound from each other in the free translatory motion of the gaseous state.

180. In regard to the mode of action in the development of vibratory motion, there are certain points worthy of notice. Firstly, the increments of motion given to the oscillating ether column by the approaching molecules would tend to rarefy the column, and drive it out circumferentially; but this is resisted by the intense ether pressure, so that the oscillating mass of ether is forcibly curbed between the opposed vibrating molecules, and thereby its vibratory motion has to bear the full brunt of the collision, the intensification of the vibratory motion of the elastic column being greater, the greater the velocity of approach of the molecules; and from this latter fact it may be inferred that, however great the velocity of approach might be, the molecules could never come into contact.

This point may be illustrated if we suppose an elastic sphere to be rebounding between two parallel surfaces at a slow rate: then if it be attempted to make the surfaces approach quickly by using great force, the impulses given to the sphere would be such that it would be a complete impossibility to bring the surfaces together, and the greater the force used, the greater is the resistance encountered; and however great the energy of the impulse given to the surfaces to make them approach, it would only cause the sphere to rebound with greater energy, the force used defeating itself. The same point might even be roughly illustrated by attempting to bring down the hand suddenly upon an indiarubber ball which rebounds between a horizontal surface and the hand, when the greater the energy used the greater will be the energy with which the ball repels the attempt to shorten its path. The same considerations apply to any intercepted oscillating mass of matter whatever, as to the previous case of the oscillating mass of ether between two opposed vibrating molecules in the act of rapid approach. It is important to observe that by the approach

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of the opposed vibrating molecules, not only are the pulsations of the intercepted ether column intensified on account of the velocity of approach itself, but also on account of the rapid shortening of the intercepted column attendant on the approach of the molecules, the number of the successive reflections of the impulses backwards and forwards between the opposed molecules increases rapidly as the molecules approach; and since a fresh impulse is received at each successive reflection, the vibrating energy of the column therefore rises in a rapid ratio as the molecules come into proximity.

181. It would be difficult, perhaps, to form a just idea of the intensity of the vibrating energy that must be developed by the collision of matter at cosmical speeds, which are so beyond comparison with any terrestrial velocities. One of the finest illustrations of the effect produced by these high speeds is afforded by the passage of those masses of matter termed "meteors" through the earth's atmosphere, when the molecules of air at their successive collisions rebound with an accession of vibrating energy equal to that of flame, and the mass itself is dissipated in vapour.

182. In the case of matter coming together at a high speed under the long-continued action of gravity, the same considerations apply as to the general case of collision, i.e. *translatory motion is converted into vibratory motion, and then reconverted into translatory motion.*

The difference in the effect is, therefore, merely one of degree, not of kind. Thus, for example, if we suppose the case of two billiard-balls which come into collision at an ordinary speed, then translatory motion is converted into vibratory motion (heat), and then reconverted into translatory motion; the feeble vibratory motion developed being merely sufficient to cause a slight recession of the molecules without separating; but if we suppose the balls to come together at a cosmical speed (say at fifty miles a second), the vibratory motion developed would at its conversion into translatory motion cause the rebound of the integral molecules of the balls in the form of dissociated vapour at the temperature of flame.

It may be observed, that on account of the possible long continuance of the propulsive action in the case of gravity, the final speeds attained may be very much greater than in the case of chemical action, so that by the approach of matter under the action of gravity, the vibratory motion developed may be such, that at its conversion into translatory motion, the chemical elements of the entire quantity of matter may be dissociated.

183. Taking, therefore, the case of a quantity of matter which has approached a common centre at a high speed under the action of gravity, then the whole body of matter would after the collision be propelled backwards to a considerable distance by the expansive action of the translatory motion of its component molecules,

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the whole quantity of matter expanding over a large radial area in the form of a nebulous mass of incandescent vapour.

Since this expansion can only take place in direct opposition to gravity, part of the translatory motion of the gaseous molecules would be thereby expended on the ether in overcoming the action of gravity; and since this translatory motion is derived from and sustained by the vibratory motion, the conversion of vibratory motion into translatory motion at the expansion of the vaporous mass would be attended by a large expenditure of vibratory motion (a large absorption of heat). The heat would thus be greatly moderated by the extensive expansion taking place.

These physical conditions would be specially adapted for the eventual development of a large supply of heat, in the subsequent extensive contraction of the nebulous mass under the action of gravity as the cooling down proceeds, and also by the eventual combination and subsequent gradual approach of the molecules of the dissociated elements as the temperature decreases.

The more intense the development of heat, the more rapid is necessarily its dissipation in the surrounding ether. The above train of physical causation would, therefore, have the effect of preventing the extremely rapid dissipation of heat that would occur were the entire energy of the approach allowed to remain in the form of heat. But in the actual fact the intense initial heat lasts but an infinitesimal instant of time, a great part of the heat being instantly converted into translatory motion at the rebound of the molecules and the attendant extensive expansion of the vaporous mass; the development of heat being thereby moderated, and at the same time a train of physical conditions is prepared such that an eventual slow development of heat takes place, whereby a supply of heat becomes available for a long subsequent period.

184. It is a generally admitted point that the sun is losing a greater amount of energy in the form of heat than is being supplied. But is the cooling down of the sun and other stellar suns of the universe into inactive masses of cold dead matter to be the final end? We may observe here, in connection with this subject, that the deductions to which we have been led, on necessary theoretic grounds, relative to the weakening of the molecular actions generally, or the weakening of the action of the ether upon molecules, attendant on a reduction of the vibrating energy of the molecules (reduction of temperature), would appear to have a direct bearing on this subject; for the working of physical phenomena, consisting fundamentally in movements of approach and recession, and a recession being absolutely necessary to a second approach; this weakening of the molecular action attendant on a reduction of vibrating energy would be the physical condition required for that reversal of the physical process which is absolutely essential to its repetition, or to the continued working of physical phenomena, the reversal being the condition required

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for the continued action of the ether in recurring cyclical processes, as consistent with the perpetuity of natural phenomena or the continuance of physical change in the universe; otherwise, the final end of all change and activity in the universe in one uniform state of useless inaction would be the inevitable result of natural causation.

It may, therefore, be observed here, as having a special bearing on this subject, that the theory of "potential energy" and "action at a distance" would necessarily involve the assumption that natural causation is so constituted as eventually to bring the entire universe to a standstill or deadlock: moreover, it may be observed that this theory would also necessarily involve the assumption that, in order for the present state of things to have been brought about, a complete revulsion in the recognized working of natural causation would be required.

185. We cannot avoid the conclusion that there is even direct physical evidence of this disintegration of matter effecting itself at a low temperature, if we truly interpret the meaning of the vast quantities of subdivided and scattered material which pervades space in the form of meteoric matter, as dust, &c., and which it is necessary to conclude must pervade space in every direction, since this disintegrated matter has been actually traced to the paths of comets, which class of bodies is known to pervade space in every possible direction.

That the existence of this vast quantity of disintegrated matter must have a purpose and a most important part to play in physical phenomena must be at once evident. The number of meteor systems contained even within the limited range of the solar system is considered on valid grounds to amount to millions, even the narrow track of the earth being known to pass through hundreds of these systems. What must, therefore, be the fact if we regard the vast volume of space separating the stellar suns? What could be the origin or purpose of this vast quantity of disintegrated matter if this be not the disintegrated material of former suns on its course towards the formation of new suns, or rather nebulæ? If we were to give an opinion on this question, we should be led, on theoretic grounds, to infer that the order of the great cyclical chain of phenomena was: *Nebula—Sun—Meteoric matter—Nebula;* and that in the present day we have physical phenomena in all these stages, the present being in this respect a type of the past, and that although continual change is going on, and there may be no actual repetition as regards distribution and quantity of matter, still the changes of the universe take place in one fundamental order of succession, in recurring cyclical processes, as consistent with the perpetuity of natural phenomena, and the continuance of physical change and activity in the universe.

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SECTION XXV.

THE ELECTRIC PHENOMENA.

186. Before proceeding to touch upon the effects comprised as the "electric" phenomena, we will in the first place consider briefly the production of motion at a distance, or the transmission of signals as a mechanical problem. Firstly, we may note that there are two possible methods of producing motion at a distance: the one consisting in the transmission of matter across the intervening space to the object to which it is desired to communicate motion; the second method consisting in the transmission of motion (in the form of an impulse or wave) along a train of matter which exists in the intervening space between the object to which it is intended to impart motion.

The first of these methods is evidently but a clumsy mechanical device; for to maintain an entire train of matter in motion at once, or to transmit continuously a stream of matter across the intervening space in order to communicate motion to an object, would especially be ill adapted to long distances; the maintenance of the train of matter itself in motion requiring perhaps as much work as the movement of the object.

On the other hand, by the second method there is no actual transmission of matter, and therefore the resistance due to the bodily propulsion of a train of matter across the intervening space is entirely avoided; there being also other special mechanical advantages in the method of producing motion at a distance by waves, which we shall have occasion to refer to.

187. The action of the apparatus known as the "pneumatic bell" may serve as a practical illustration of this latter method. The arrangement consists essentially, as is known, of a tube containing air, along which a wave is transmitted, due to any disturbance produced at one end of the enclosed column of air, by which means the motion serving as a signal is produced at the farther end of the air column.

Regarding the mechanism of the arrangement, we have here in the form of the air column enclosed within the tube a train of matter consisting of small masses (the molecules of air), among which a rapid interchange of motion is continually going on, so that it becomes only necessary to disturb in any way the motion of these small masses at one extremity of the tube, when by a self-acting mechanism the disturbance is propagated with rapidity to the opposite extremity, the small masses simply exchanging motion and propagating the signal at their own normal velocity.

Here we have the best conceivable mechanical arrangement

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for the transmission of signals; indeed, it may be said that if one were to attempt *à priori* as a mechanical problem to scheme out the best or simplest conceivable device for the transmission of signals, the principle involved in this mechanism of the air column would constitute the only true solution to the problem.

188. In principle, the conditions required to satisfy the problem evidently are, first, to have a train of matter in rapid and continuous motion, so as to be disposable at any time to transmit a signal at a high speed, without the necessity for imparting to the train of matter the motion by means of which it transmits the disturbance producing the signal. Secondly, in order that this train of matter may be always at disposal, it is necessary that the motion of the parts of the train should take place in such a way that the train of matter, as a whole, preserves a fixed position, and is maintained in equilibrium. Thirdly, in order to render a high speed practicable without disturbing effects, the moving masses must be small, so that each by itself is incapable of producing disturbing effects.

These are precisely the mechanical conditions fulfilled in the simplest conceivable manner in the case of the air column by which the signal of the pneumatic bell is transmitted. In order to transmit a signal, it is only necessary to disturb, i. e. to increase or diminish, the normal velocities of the air molecules at one end of the column by an amount however small, when the disturbance is transmitted automatically, at the normal speed of the air molecules, to the farther end of the column.

If the column consisted of hydrogen gas, the normal speed of whose molecules exceeds by about four times that of the molecules of air, it would be possible to transmit a signal at about four times the speed.

It serves well to show the incomparable superiority of the method of transmitting signals by waves as contrasted with the clumsy device of transmitting a stream of matter, when it is considered that in order to produce a signal at the velocity of an air wave by the transmission of matter, it would be necessary to propel the stream of matter through the tube at the speed of a bullet. The friction and resistance in such a case may be well imagined.

189. Since the mechanism of the air column in the tube of the pneumatic bell is a type of the external air, the same considerations equally apply here, and would therefore indicate the admirable adaptability of the air as a mechanism for the transmission of motion to a distance, or as a means of intercommunication, as illustrated, for example, in the case of those waves of special periods which, by the motion transmitted to the auditory nerve, produce the sensation of sound: the same considerations also applying to the perfectly analogous mechanism of the ether as concerned in the phenomena of light.

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It would surely be difficult to imagine a more admirable or sensitive mechanism than the molecules of air impinging against a musical string, ready to take up every gradation of movement of the string and transmit it to the auditory nerve, the slightest movement of the string affecting the normal velocities of the air molecules, which automatically exchanging velocities transmit the motion to a distance, the air in its physical constitution forming a mechanism of extreme delicacy and precision, and of the *simplest conceivable* character; and just as the molecules of air impinging against a musical string constitute the simplest and best-adapted mechanism for taking up every movement of the string, and transmitting it by interchange of motion to the auditory nerve, so the smaller scale but perfectly analogous mechanism of the ether constitutes the simplest and best-adapted mechanism for taking up every movement of the smaller scale masses (molecules), and transmitting it to the visual nerve.

The fact of the mechanism of the ether and air being the *simplest conceivable*, and the consequent *similarity* of the mechanism in both cases, therefore constitutes an illustration of the mechanical principle that to produce complex effects with precision and accuracy the mechanism concerned *must* be *simple;* the wonderful complexity of the phenomena of sound and colour rendering it equally indispensable in both cases that the mechanism producing these effects should be of the *simplest* character, without which precision and accuracy in the transmission of the motions would be impossible.

190. Turning now to the consideration of the electric phenomena, and taking the observed fact that a signal can be transmitted through a wire at about the speed of light, we have to inquire as to the possible physical processes by which such a result can be attained. There exist in principle but two conceivable methods: first, the propulsion of a stream of matter through the molecular interstices of the wire at the observed speed; secondly, the transmission of an impulse or wave along the wire. The first method in this case will scarcely bear a serious consideration, for even if it were conceded that a sufficiently distinct idea could be formed of the nature of so-called "fluids" to warrant the hypothesis of their existence, the idea of propelling bodily a stream of fluid some thousands of miles in length, at about the speed of light, through a wire with open lateral spaces between the molecules, cannot but be regarded as unmechanical in the extreme; indeed, the idea would have some resemblance to an attempt to force water through a pipe with sides of open network. We do not imagine that the fluid hypothesis is at all seriously entertained, the term "electric fluid" being perhaps rather used as a convenience than anything else. The fact of the appreciably uniform rate of transmission of electricity, whether great or small force be employed, itself is sufficient to prove that it is not a *fluid*

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which is transmitted; for if anything were propelled through the wire, the rate of passage would depend on the propulsive power employed, and it would be wholly unaccountable that the rate of transmission should be always about equal to that of light, independent of the will of the operator. If, therefore, nothing be propelled through the wire, then the signal can be only transmitted by something already in the wire, in the form of an impulse or wave. It may also be noted that this appreciably uniform rate of transmission, independently of the force used, is one of the known and essential characteristics of a *wave* motion.

191. Regarding the structure of the wire, we have a series of molecules at certain distances apart, maintained in positions of stable equilibrium under the action of the ether which surrounds the molecules and pervades the molecular interstices of the wire, the ether within the wire forming an unbroken train of matter, since the molecular interstices necessarily communicate with each other.

There exist, therefore, two possible modes by which a wave can be transmitted along the wire, viz. either by the ether independently, or by the ether and the molecules conjointly; for since the molecules are separated by the ether, it would be impossible for the molecules themselves to transmit a wave independently, i. e. without the participation of the ether.

Now, on considering the question, it becomes tolerably apparent that the transmission of the wave by the molecules and the ether conjointly, involving as it does a continual change of motion between dense and light masses, would be far too slow for the speed of electricity. If the molecules at one end of a wire be disturbed from their positions in any way, then this movement produces a change of the ether pressure upon the adjacent molecules, which causes their movement, and thus a wave is transmitted along the wire at a certain rate dependent on the promptitude with which the disturbed molecules recover their positions of equilibrium, which varies with different substances, the velocity of this species of wave transmitted by the molecules and the ether conjointly, being given by the velocity with which the substance transmits a wave of sound. Since, however, the velocity of transmission of such waves will not bear comparison with the speed of electricity, we are bound to reject the assumption that the molecules are concerned in the transmission of the waves producing the electric effects, and we are therefore reduced to the one remaining possible solution to the problem, viz. that the wave is transmitted by the ether independently.

192. It may also be observed that the velocity of transmission of a wave propagated by the molecules of a substance would necessarily depend on the molecular structure of the substance, the velocity varying considerably with different substances; whereas this has not been observed to be the fact in the case of

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electricity; indeed, the appreciably uniform rate of transmission of electricity in materials of the greatest diversity would by itself warrant the inference that something independent of the materials themselves, but present in all, would be the agent concerned in the transmission of electricity. The ether would satisfy this condition, and it may be observed, lastly, that the ether alone (as indicated by the speed with which it transmits a wave of light) possesses in the normal motion of its particles a velocity at all adequate to propagate, by interchange of motion, a small disturbing effect to a distance with the speed of electricity.

193. As regards the mode of transmission of the waves producing the electric effects, precisely the same considerations in principle apply as in the case of the air column of the pneumatic bell, only the particles of matter in the form of ether have a very much higher normal velocity, the train of ether in a metallic wire forming an analogous, beautiful, self-acting mechanism for the transmission of signals, it being only necessary to disturb in any way this moving train of matter at one extremity of the wire, when the disturbance is propagated in the form of a wave to the opposite extremity. The mechanism is automatic and of the simplest conceivable character, the wave being propagated simply by the re-establishment of the equilibrium of motion along the circuit.

At the same time the system of waves or impulses forms the suitable mechanical adaptation for producing by vibration that disturbance or change in the ether pressure about the apparatus employed, by which the various motions forming signals are produced.

194. Continuous motion of some kind constitutes the only possible physical means by which a disturbance or change of the ether pressure can be permanently maintained; for since the ether penetrates freely the molecular interstices of matter, it becomes impossible to maintain a permanent change of pressure by using matter as a barrier to exclude the ether, as can be done in the case of the air (by the evacuation of air); so that continuous motion alone (i.e. the motion of a mass or molecule of matter, or of a portion of the ether itself), by affecting the velocities of the ether particles, and thereby excluding the ether by rarefying it, can produce a permanent change of the ether pressure.

It will become evident, on considering the question, that a vibratory form of motion is the only form of motion mechanically adapted to this purpose; for since the disturbance or change of the ether pressure is maintained at a fixed spot, the moving mass, therefore, which produces the disturbance must have such a form of motion that it can maintain a fixed position and yet disturb the ether. For reasons already indicated, a vibratory form of motion is in principle the only form of motion adapted to satisfy these conditions; for by this form of motion the moving mass of matter

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or ether can maintain a fixed position by oscillating about it, and yet can disturb the surrounding ether and produce a change of pressure.

195. The above considerations as to the mode of transmission of electricity may serve to remove any difficulty that might have existed in appreciating how an electric signal can be transmitted at such an immense speed with the feeble means employed, the real state of the case being that the velocity of transmission is not generated at all, but *exists already;* it being only necessary to change (increase or diminish), by an amount however small, the normal velocities of the ether particles at any point of the circuit, when the disturbance is propagated by the simple re-establishment of equilibrium along the whole length of the circuit, and thus by the feeble disturbance produced by a drop of acid, a signal may be sent thousands of miles with the velocity of light.

It appears a reasonable conclusion that the velocity of transmission of the wave might be affected to a certain, relatively small, extent by the presence of the molecules of the circuit, the wave probably undergoing inflection; also, it may be observed that the normal velocity of the ether particles upon which the velocity of transmission directly depends, is affected to a certain, relatively small, extent by the vibrations of the molecules.

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APPENDIX.

BEING obliged to conclude here, for the present, we will merely give a short summary of conclusions regarding certain fundamental points, to which we have been led as the natural deductions resulting from the previous inferences regarding the part played by the ether in physical phenomena, reserving a more detailed consideration of the subject to a future opportunity.

Firstly, when an electric circuit is interrupted the waves are reflected, necessarily producing *stationary* waves. "*Static*" electricity, or the "*static*" electric state, therefore consists in *stationary* vibrations of the ether in the interior of a body when said to be "charged," these vibrations also disturbing the external ether and producing the phenomena of "attraction" and "repulsion" characteristic of vibratory motions.

Since, also, the ether within a mass of matter or "conductor" is freely movable, the plane of the waves can therefore shift itself. Thus, when a charged metallic sphere is surrounded concentrically by matter, such as by the appreciably uniform distance of the walls of a room, then the waves are also concentric, and radiate in stationary vibrations on all sides. But when a plane metallic surface is approached near the charged sphere, then the stationary vibrations are necessarily intensified by reflection between the two, the conditions of equilibrium causing the plane of the waves to swing round and become parallel to the plane surface; the lateral energy of the waves is therefore taken off, and concentrated between the opposed surfaces, the sphere accordingly now only appearing "charged" on that side where the plane is situated.

The special action of points will be clear when it is considered that a mass of aeriform matter in stationary vibration tends to expand in every direction, and would therefore act with special energy along a point when a point is fixed to a charged conductor.

It is evident that friction or any molecular disturbance whatever would naturally throw the ether within a mass of matter into vibration. The stationary vibration of a mass of ether has its analogy in the stationary vibration—"resonance"—of a mass of air, produced by friction, &c. The change of "*static*" electricity into "*dynamic*" electricity, or the "*static*" state into the "*dynamic*" state, and conversely, is simply the change of *stationary* vibrations into *progressive* vibrations, the one of these being necessarily always capable of producing the other.

The "magnetic" condition consists in the disturbance or wave movement necessarily produced outside a circuit, such as a wire—due to the communication existing between the ether within the wire and the external ether—when a wave is transmitted through the wire.

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It is a known and remarkable fact that the electric energy within a circuit is the same at all points, however far from or close to the source of energy, and however diverse the materials may be of which the circuit is composed; this fact possibly having led to the idea of its being a *current.*

This uniformity in the energy in all parts of the circuit, and also the necessity for having a *circuit*, is explained by the fact that the vibrations of the ether outside the wire or circuit can only be in equilibrium among themselves, and, indeed, can only exist when the circuit is *complete*, and thus the oscillating masses of ether can abut against each other and be in equilibrium of pressure; just as the component stones of an arch can only be in equilibrium when there is a keystone, or when the circuit is complete. Indeed, the closed or complete circuit is one of the conditions for the existence of stationary vibrations in a medium *without* masses of matter for these vibrations to abut against, the vibrations abutting against themselves in a *complete circuit.*

The stationary vibrations of the ether between two molecules of matter exist without a complete circuit, from the fact that these vibrations can abut against the molecules; but when matter is wanting altogether in the line of the vibrations, then these vibrations can only exist by abutting against themselves, which is only possible in a *complete circuit;* and the condition for equilibrium of pressure requires that the energy of the vibrations should be perfectly *uniform* in all parts or throughout the circuit. Indeed, this uniformity is necessarily self-adjusting.

Since, therefore, the vibrations outside the circuit or wire (the magnetic vibrations) are necessarily connected with and dependent on the vibrations inside the wire, the one reacting upon and influencing the other; accordingly, therefore, the uniformity in the vibrations outside the wire is necessarily followed by uniformity inside, whatever the nature of the different materials forming the circuit. Thus when, for example (without interrupting the circuit), an additional length of wire or resistance is brought into the circuit, the energy of the internal (electric) waves first falls at or near this point of the circuit, and thus the equilibrium of motion between the internal (electric) vibrations and the connected external (magnetic) vibrations is upset at this point of the circuit, and in the readjustment of equilibrium, therefore, motion is transferred from the stronger external vibrations to the weaker internal. The energy of the external (magnetic) vibrations, accordingly, next falls at this point of the circuit, and immediately in the self-acting readjustment of the equilibrium of motion among the external vibrations, a magnetic wave rolls round the circuit, readjusting the uniformity of wave motion outside (i. e. the magnetic vibrations), and with it the uniformity of the connected wave motion inside (i. e. the electric vibrations). Thus the conditions for equilibrium require that the electric wave motion should be uniform throughout the circuit, and the magnetic vibrations cannot exist at all without a complete circuit.

The electric spark is due to the disturbance produced in the ether, attendant on the sudden change of *stationary* vibrations of the ether into *progressive* vibrations, by which the molecules of air are displaced and shaken into vibration, emitting light. It may be observed, that one of the characteristics of a *stationary* vibration of matter is that the effects are perfectly balanced, or the oscillating segments into which an aeriform medium in stationary vibration is broken up, impinge against each other

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and balance each other's effects, the nodes or points of no motion remaining stationary. But when from any disturbing cause the equilibrium of the vibratory movement of the medium is upset at any one point, and the vibrations consequently become *progressive*, then the effects are no longer balanced, the nodes shift their positions, and the molecules of matter immersed in the ether may be met on one side by a condensation, on the other by a rarefaction, as the wave passes, and thus the molecules may be displaced or driven out of their positions. Thus, in the powerful effects of lightning, for example, the sudden change from stationary to forcible progressive vibrations of the ether within a mass of rock may be sufficient to disintegrate it completely, or to shatter it to fragments.

When the human system is connected to the charged conductor of an electric machine, the stationary vibrations produced in the ether within the system are unfelt, but when by touching some external object (connecting to earth), the vibrations suddenly become progressive, a tremor is felt, or the molecules of the system are shaken, and with a sufficient power may be displaced with injurious effects. It would be difficult to imagine a more searching or effective means of disturbing the molecules or integral parts of a mass of matter than by disturbing the ether which pervades the mass; indeed, one might infer *à priori* that this would be one of the most effective means of producing powerful dynamic effects. The remarkable character of the effects of lightning, by which the most rigid structures are overthrown and solid masonry shattered to fragments, is in perfect mechanical harmony with the special nature of the physical cause concerned; a powerful pulse down the ether which pervades a tree, for example, being sufficient to split it into fibres. Indeed, the observed effect is precisely what might be expected from the nature of the physical cause, the disturbance of the ether which pervades matter to the core, scattering the integral parts in all directions, and at the same time nothing could point more unmistakably to the existence of a powerful dynamic agent—by the disturbance of whose equilibrium these effects are produced—than the observed remarkable dynamic effects of lightning.

Regarding "conductors" and "non-conductors," a "conductor" may be defined as a body whose molecular structure is such that its molecules are *least* affected by the passage of the electric waves, while a "non-conductor," or bad conductor, partly takes up the motion of, and partly reflects the waves. It is obviously merely a question of degree, not of kind; for the molecules of all substances whatever take up the vibratory movement of the waves to a certain degree, or all substances are heated by the passage of electricity, and those which are heated least, or those substances whose molecules take up the motion of the waves least, are the best "conductors," conducting power being inversely as the heat developed. A forcible wave movement of the enclosed ether may be sufficient to raise the vibratory motion of the molecules until they lose their positions of stable equilibrium, and by their vibrations break up the ether into waves of light, as illustrated, for example, by the fusion of an iron wire by the passage of powerful electric waves. The attendant disintegrating action of the wave motion is illustrated by the observed distortion of shape and occasional scattering of the parts of an iron wire at the point of fusion.

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The electric phenomena being due to a wave motion of the ether, it would be a thing to be expected beforehand that any disturbance of the molecules of substances, or any molecular disturbance whatever, would be attended by the development of electricity, as is known to be the fact. The energetic molecular disturbance of chemical action, by which the molecules are driven out of their positions, would naturally be one of the most effective means of disturbing the ether and giving rise to the electric waves, the feebler disturbing action of heat and friction producing like but feebler effects.

Note relative to the Production of Motion through Vibration.

In regard to the phenomena of attraction produced through vibration, we have found it a simple and effective method for illustrating the results, to float the masses acted upon on the surface of water. Thus the simplest method is to take a small piece of cork and insert a narrow strip of card into a slit made in the cork, the cork being then placed on the surface of water, so that the strip of card is vertical. If a tuning-fork be then struck a sharp blow and approached to the card, the latter is distinctly attracted, and may even be made to turn round by holding the prong near the edge of the card and turning the fork round in a circle. The effect is much greater in close proximity to the card. To show the marked character of the effect, the fork may be held near the card, and on the latter receiving an impulse towards the prong, if then the fork (still vibrating) be suddenly brought round to the opposite side of the card, the movement due to the first impulse is checked and changed into a movement in the opposite direction. Another experiment consists in taking a short strip of tissue paper and placing it upon a table, when by holding the vibrating prong about an eighth of an inch above the strip of paper, the latter will spring up and adhere to the prong—a film of air being intercepted between the two—the paper dropping off when the vibration ceases. The effect here reminds one of the attraction of light substances by a rubbed piece of sealing-wax.

AUG 10 1918

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

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