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LIX. *On certain hypothetical elements in the theory of gravitation and generally received conceptions regarding the constitution of matter*

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Atmospheric Changes which produce Wind and Rain," called attention to the great effect which condensation must produce; but he attributes that effect to the further expansion of the air by the latent heat made manifest, rather than to the actual loss of weight, or elastic force, in the atmospheric column. This view has also been partially adopted in the later editions of the 'Physical Geography of the Sea,' by Captain Maury, who considers that the latent heat developed by condensation may give a further expansion to the tropical air. It seems to me, on the contrary, more probable that the effect is produced by the direct statical agency of diminished pressure, and that the heat evolved is simply thrown off into space through the very thin and clear medium of the upper atmosphere.

Whether this is the case, or not, it is difficult (perhaps impossible) to decide; but I submit that I have shown strong grounds for believing that, in whatever way it acts, sudden condensation of aqueous vapour is the principal cause of the trade-winds, of their inflection towards the west coast of Africa, and of the Indian monsoons, in opposition to the theory which would derive these winds from the mere expansion of the intertropical air by heat.

LIX. *On certain Hypothetical Elements in the Theory of Gravitation and generally received conceptions regarding the Constitution of Matter.* By James Croll*.

Gravitation.

No future researches or discoveries in physical science will ever overturn Newton's grand theory of universal gravitation, or ever in the least degree shake universal confidence in its truth. It will stand as the immoveable foundation upon which the whole superstructure of physical science will for ever rest. Although the truth of everything that is really essential to the theory is established beyond the possibility of a doubt, yet there are certain hypothetical elements which have been unnecessarily associated with it, or rather included in it, which by no means can lay claim to be considered as established. I shall briefly refer to a few of these elements.

Gravity is commonly defined to be an "attractive force between the particles of matter varying inversely as the square of the distance." Or, as stated more fully, "every particle of matter in the universe attracts every other particle with a force varying inversely as the square of their mutual distances, and directly as the mass of the attracting particles." It will be seen at once

* Communicated by the Author.

that this definition contains something more than a mere statement of the facts determined by observation. It contains a hypothetical explanation of the facts.

Let A and B be two particles of matter. We know experimentally that they tend towards each other with a force inversely as the square of their mutual distance; but the ordinary definition of gravity goes further than this. It not only asserts that they tend towards each other, but it asserts that this force or tendency arises from A attracting B, and B attracting A. It asserts that B moves towards A *because* B is attracted by it.

It was demonstrated by Newton, and has been proved by general observation and experience, that bodies tend towards each other with a force varying inversely as the square of the distance, and directly as the mass of the bodies. But it never was demonstrated or proved by any one that the bodies *attract* each other. The thing which has been demonstrated is that B tends towards A: but the theory does not rest here; it goes on to account for this tendency by referring it to a hypothetical cause, viz. to the "attraction" of A. This, however, is a mere hypothesis and no way essential to the theory. All that the theory requires is that it be demonstrated that A tends to move towards B. It is not necessary that we should go beyond this, and attempt to explain the cause of this tendency.

Trifling as this assumption, included in the theory, may at first sight appear to be, it will be found that almost all the difficulties and objections which have been urged against the theory of gravitation are due, in some form or other, to that assumption. At the very outset we have the objection urged against the theory that it implies the absurdity of action at a distance. Now the mere facts of gravitation imply no such thing. That A and B placed at a distance should tend towards each other does not imply any action at a distance. A moves by virtue of a force, but it does not follow that this force is at a distance from A. But if we assert that A and B "attract" each other, then we imply action at a distance; for A is then affirmed to move in consequence of the force of B, and B in consequence of the force of A. "The very idea of attractive force," as Professor Brücke remarks, "includes that of an action at a distance."

No principle will ever be generally received that stands in opposition to the old adage, "a thing cannot act where it is not," any more than it would were it to stand in opposition to that other adage, "a thing cannot act before it is, or when it is not"*. It probably was with the view of reconciling this hy-

* For an account of the metaphysical origin of these adages, see a work by the author, 'Philosophy of Theism,' p. 112. Walford, Jackson, and Hodder. London, 1857.

pothetical part of the theory with the adage in question that led Sir Isaac Newton to suggest that gravity might be transmitted by means of an æthereal medium existing in space.

Another objection is this: if another particle C be placed beside B, it will be found that A will attract C with as much force as it does B, and yet continue to attract B the same as though C had not been added; and if we add another particle D, this particle will also be attracted with equal force, the other two remaining as strongly attracted by A as though D had never appeared. We might in like manner go on adding particle to particle to infinity, and still A would continue to attract each new particle as it appeared with as much force as though no other particle were in existence. In fact there is no limit to this attracting power of A. This is contrary to what we know of the character of force in every other department of nature.

Another objection also follows; when we add C to B and thus double the attraction, A doubles its force also and attracts them with as much force as they attract it. If D be added, the attraction is tripled, but A triples its force also; and we might proceed in this manner adding particle to particle until we had added to B every particle in the universe, and yet, strange to say, the single particle A would attract the entire universe with as much force as the universe attracted it.

The attraction theory is also in opposition to the principle of the Conservation of Force, as has been shown, I think, clearly by Faraday*. When a stone, for example, is thrown upwards from the earth, it not only loses all its motion, but it loses its attraction in proportion to the square of its distance from the centre of the earth. What becomes of the motion imparted to the stone? It is not transformed into attraction, for the attraction diminishes as well as the motion. When the stone again falls to the earth, it gains both motion and attraction. In the former case the attraction is said to consume the motion, and, instead of becoming stronger, becomes weaker in consequence; and in the latter case it imparts this same motion, and yet, after imparting the motion, it is actually found not only not to have lost, but to have gained force thereby. Faraday justly asks what becomes of the force or motion imparted to the stone? It is not converted into attraction, for the attraction becomes less instead of greater in consequence. And in the case of the falling stone, where does the motion come from? If the motion arises from the attraction of the earth, then there must be a certain amount of this attractive force converted into motion; and if so, the attractive force should be so far reduced; but instead of this, it is actually increased. There is, therefore, no account given

* Phil. Mag. for April 1857.

of what becomes of the motion externally imparted to the stone when throw nupwards, or where the increase both of attraction and motion is derived as it descends. If the attraction theory be correct, then there is a destruction of force in the one case, and a creation of force in the other; and if so, then the principle of conservation of force is violated.

Professor Brücke tries to answer Faraday's objections in the following manner:—"Let the mass A," he says, "be separated from the mass B by an external force; while this separation takes places the attraction diminishes, the attractive forces being in the inverse ratio of the squares of the distances. Where abides the force which is here destroyed? The reply is: If the mass A be left to itself, it moves back towards B, and when it has arrived at its original position it will be attracted by B with the same force as before; besides this, it has attained a velocity, half the square of which, multiplied by the mass of A, is exactly equal to the work which was formerly expended in removing it from B. There is therefore no force destroyed by the change which the external cause has wrought; but just as much force appears at the end as was expended in producing the change"*.

It will be easily perceived that this never touches the objection. Faraday will admit that when A *has returned to its original position*, it will have received back all the force that was lost. When A is removed from B by an external force, the motion disappears without producing any apparent effect; it does not appear under any other form of force; and when A approaches B, motion is produced without the expenditure of any force. There is therefore an unaccountable loss of force in the one case, and as unaccountable a gain of force in the other case. Consequently when A reaches B it will be in the same state as when it left; for the loss in the one case is compensated by the gain in the other. But this never explains what became of the force which was lost in the first case, or whence was derived the force which was gained in the latter case. If a man who had lost in some unaccountable manner £10 the one day and gained in an equally unaccountable way £10 the next day, were to inquire what became of the money lost on the first day, and whence came the money gained on the second, it would be no answer whatever to tell such an individual that he was just as rich at the end of the second day as he was at the beginning of the first. It would of course be a somewhat satisfactory answer to be told that the money gained the second day was what had been lost the first; and this no doubt is the idea Professor Brücke wishes to convey. When the stone is thrown upwards, he supposes that the motion or energy imparted becomes stored up in the

* Phil. Mag. February 1858.

stone under a new form, and when it returns to the earth the energy thus stored up is given back in the form of motion as before. To express the matter in more precise terms—when the stone is thrown up, the *vis viva* becomes less and less, and when it reaches the turning-point it is zero. But at this point the whole energy as a cause of motion is stored up, the *vis viva* is transformed into tension, *actual* or *kinetic* energy into *potential* energy.

That this is not a satisfactory explanation is evident. For when the stone is thrown upwards, the motion imparted gradually disappears. It is not converted into attraction, for the attraction, instead of being augmented by the loss of motion, is found to decrease also. Hence experience shows that, according to this theory, both the kinetic and the potential energy decrease as the stone rises.

No truth in physical science is now better established than that force is indestructible. If it ceases to exist under one form, it is because it has assumed some other form. Any conclusion which stands in opposition to this principle must be abandoned, whatever may be its claims for reception on other grounds. When, for example, we observe the loaded piston rising under the pressure of the steam, we at once conclude that the energy being manifested as mechanical work existed the instant before under the form of heat, and that the heat in turn existed previously as chemical affinity in the coal and the oxygen of the air. And again, the potential energy of the coal existed in some former age as sun-rays.

When we observe mechanical work performed by heat, or by electricity, or by magnetism, &c., we at once infer that there *must* have been a consumption of these forces corresponding to the amount of work performed; but, strange to say, although we are continually witnessing the mechanical effects produced by gravity, yet we are most reluctant to admit that the mechanical force manifested previously existed as gravity. When a stone, for example, falls to the ground, and by the concussion generates, say, 100 foot-pounds of energy in the form of heat, it is at once admitted that the 100 foot-pounds of energy appearing as heat was derived from the mutual attraction of the earth and stone. But how few will admit that there has been a consumption of gravity; and yet it is self-evident that if the total amount of the earth's gravity be as great after the stone has reached the ground as *before it commenced* its descent, then there must have been a creation of power. The principle of conservation necessitates us to conclude that when heat, *vis viva*, or work of any kind is produced by gravity, what we gain of actual energy in the form of *vis viva* &c. we must lose of potential energy in the form of gravity. No one would for a moment think of denying the correctness of this mode of reasoning in regard to heat, magnetism, electricity, or any other form of force. Why, then, make an exception in the case of gravity? But more than this, the very idea of an exception is in itself absurd; it is nothing less than to make an exception in regard to a principle which we admit holds universally true.

To reconcile the common conceptions of gravity with that of conservation, it has been said that the potential energy of gravity does not simply consist in the tendency which bodies have of approaching to each other, but consists also in the distance through which that tendency is capable of continuing to act. For instance, when two bodies approach each other under the mutual influence of their gravity to one-half their former distance, their potential energies are diminished also to one-half (although their tendency to approach is not diminished), because the distance through which that tendency is now capable of acting is but one-half of what it was formerly.

The energy of a raised weight, for example, it is said is the product of the gravitation-pull upon it, and the distance through which this pull can act.

$$\left.\begin{array}{l}\text{Energy, or work performed}\\ \text{by descending weight}\end{array}\right\} = \left\{\begin{array}{l}\text{Force, or pull of gravitation}\\ \text{upon the weight} \times \text{distance}\\ \text{passed over by descending}\\ \text{weight.}\end{array}\right.$$

Or,

$$\text{Energy} = \text{a force} \times \text{a length.}$$

It is certainly true that the amount of energy or work performed is proportionate to the pull of gravitation × the distance through which the weight descends. But I am unable to perceive how this can meet Faraday's objection; for it seems perfectly evident that the mere change of relative position cannot constitute any form of force. Distance is a necessary *condition* to the transformation of the potential energy of gravity into the actual energy of *vis viva*, or of heat, &c.; but distance itself does not in any degree constitute this transformation. When bodies arrive at contact, there can be then no further transformation of potential energy into kinetic; not because the potential energy has been all consumed, but because the bodies are not in a *condition* to allow of any further transference. The *tendency* to approach, though increased to infinity, would not help in the least degree to produce any further transformation of potential energy into kinetic; for the thing wanted is not more potential force, but the necessary condition to transference. That which causes bodies mutually to approach with velocity and thus produce actual energy is not the fact that they are *separated*, but the fact that they *tend* toward each other. Distance is a necessary condition to the action of this tendency, and, of course, the greater the distance the greater is the opportunity for acting; but when kinetic energy is produced in the form of *vis viva* or heat, &c., by the approach of bodies, the equivalent in the shape of potential energy lost is *tendency*, or *gravity*, not *distance*. The foot-pounds of kinetic energy produced existed previously in the statical condition of a *tendency* to approach, not in a mere *relation of coexistence in space*.

Let us take the case of the steam-engine. We have here also two elements, the potential and the kinetic. We have (1) the potential element consisting in the dead pressure of the steam in the interior of the cylinder, (2) the *vis viva* and mechanical work produced as the piston rises under the pressure. This is simply a transference of force from the one condition to the other. What we gain in *vis viva* and mechanical work we lose in pressure. But space is a *condition* as necessary to the transference of pressure into *vis viva* as of gravity into *vis viva*. No matter what the pressure may be, if the piston is at the end of its stroke, and has no further space through which to move, no transference can possibly take place. The equivalent gained in *vis viva* and mechanical work is wholly derived from the pressure of the steam, not from the space. Space is simply a *condition* in the transference. The matter is precisely the same in the case of *vis viva* generated and work performed by gravity. The actual energy of the falling stone must be entirely at the expense of the dead pull of gravity, the space being simply a condition in the transference. The same reasoning is equally applicable to the conversion of statical electricity into dynamical, or of magnetic force into mechanical work. Unless a path is opened up between the ends of the battery through which the forces may travel, no transference of statical into dynamical electricity can possibly take place. Unless the magnetic engine is allowed to move, the magnet does not lose any of its potential energy. In fact space is a necessary condition in the transformation of force under all circumstances. It seems to be metaphysically absurd to suppose that either *space* or *time* can be in the operations of nature anything more or less than simple *conditions*.

The work performed by a water-wheel, for example, is as really and truly derived from the pull of gravity as the work performed by the rising piston is from the pressure of the steam. And it is just as absurd to assert that the pull of gravity is not diminished by the motion of the wheel, as to assert that the pressure of the steam is not diminished by the rising of the piston.

It is, of course, perfectly true, as has been stated, that the work performed by gravity is in proportion to the pull of gravitation × the distance through which the pull can act. And the work performed by the piston is in proportion to the pressure of the steam × the length of stroke. But then, if space be nothing more than a condition in the operation, the energy must be derived from the pressure, not from the space. The gain of energy, or the work, would be in this case exactly equal to the loss of pressure or force, the space being simply the condition which allows the change from force to energy to take place.

Time and space are necessary conditions in all phenomena, whether of mind or matter, but they are mere conditions. We believe, in opposition to Kant, in the objective reality of time and space; but still, though space is an objective reality, a thing in itself, it can no more be converted into a force or an energy than it can be converted into a stone. The one supposition appears just as extravagant and absurd as the other. It is just as violent an assumption to suppose that time could be converted into *energy*, become an efficient cause in the performance of work, as that space could be so converted. Space has been eternally space, and can *absolutely* be nothing else.

But supposing that space could be something more than a mere condition in the transference of the force of gravitation into mechanical energy, still this would not reconcile the ordinary theory with the principle of conservation.

In the case of the loaded piston rising under the pressure of the steam, we have the pressure of the steam and length of space both diminishing as the *vis viva* or mechanical work increases. This is in harmony with the principle of conservation, for pressure or force diminishes as energy or work increases. But in the case of gravitation matters are reversed; for the force increases along with the work. As the weight descends and performs work, the pressure of the weight, the thing which performs the work, increases also. And when the weight is rising and energy diminishing, the force or pressure of the weight is not increasing but actually diminishing also.

This difficulty, along with all the others which we have been considering, will entirely vanish if we adopt the view of gravity which has been ably advocated by Faraday*, Waterston†, and other physicists, viz. that it is a force pervading space external o bodies, and that on their mutual approach this force is not ncreased as is generally supposed, the bodies merely pass into a place where the force exists with greater intensity; for in

* Phil. Mag. April 1857. Proceedings of the Royal Institution for 1855.

† Phil. Mag. S. 4. vol. xv.

such a case the intensity of the force, in the space external to any body, is inversely as the square of the distance from the centre of convergence of these lines of force. As the stone recedes from the earth, its *vis viva* is transferred to space and exists there as gravity. When the stone approaches to the earth, the force existing in space is transferred back to the body and appears again as *vis viva.*

"The integral gravitation," says Mr. Waterston, "is a function of space. . . . . . Each element of radial distance has associated with it a fixed element of mechanical force, to be given or taken from all bodies traversing it."

Matter.

Commonly associated with the hypothesis that the atoms of matter attract each other at a distance is another hypothesis, in regard to the physical nature of the atoms themselves.

The common conception of matter, which however is now beginning to be abandoned by many of our leading physicists and chemists, is that all matter consists of atoms essentially solid, indivisible, impenetrable, and infinitely hard. The conception is, that matter is solidity occupying space. It is almost needless to say that this conception is wholly hypothetical. It is not a simple representation of our experience of matter, but rather a hypothetical attempt at an explanation of the cause of that experience. What we experience is resistance. Matter offers resistance to the touch, and we say that it is hard. An atom or particle of matter will maintain length, breadth, and thickness against any pressure, however great, applied to deprive it of volume. Nothing can deprive the atom of the possession of a certain amount of space; hence it is asserted that it must be infinitely hard—in short, a part of space filled absolutely solid. This hypothesis also assumes the resistance thus offered by the atom to be purely static or passive resistance.

That this hypothesis is not necessary to account for our experience of matter will appear obvious from the following considerations:—Were a cubic inch of space to become, by some means or other, impenetrable (that is, were it to resist the approach of all bodies into it), even although it were *completely void,* this cubic inch of empty space would appear to the senses in every respect to be solid. And were a cube of what is considered solid matter of the same size placed beside it, we could not by any known means determine which of the two was the solid one.

All that is necessarily implied in matter, so far as what is called hardness or solidity is concerned, is that it is either a *power* of resistance in space, or a *substance* which manifests resistance as a property. If we consider this resistance to be an *effect,* and not a property or quality, the most philosophic way is to say, with Faraday *, that the atom is simply a centre of force, and what we call matter is simply a power of resistance acting in a certain part of space, thus making no hypothetical statement of any kind regarding the nature of this cause or power.

But the hardness or resistance manifested to our experience is considered by those who adopt the ordinary theory to be a property or quality of a substance, not the effect of a cause. But this does not afford any warrant for assuming the existence of solid impenetrable atoms. It will not do to say that there can be no resistance without solidity. All that we require to affirm is that there must be a something possessed of the property or quality of resistance—a something which manifests itself as resistance in space. What we must believe is that there exists a substance or subject to which the resistance belongs.

The necessity for assuming the existence of a something to which these properties belong is purely metaphysical. The metaphysical necessity under which we lie obliges us to postulate the *existence* of a something; but it does not necessitate us to form any conceptions regarding the nature of this something. Its nature can only be learned by experience, through the properties manifested. If we experience resistance in space, then metaphysically we must assume the existence of a something which resists. This is all. We are not warranted from this property manifested to begin and speculate on the nature of this something. If it should manifest other properties than resistance, these other properties will give us further information regarding its nature. But if it does not manifest any other property than simple resistance, all that we can ever possibly say is that a something resists, but what this something actually is, further than a power of resistance, must in such a case remain for ever unknown. Some even believe that if you deprive matter of that imaginary quality called solidity you annihilate it altogether. Of course, if solidity be a property of matter, and you annihilate the solidity, you annihilate matter as a something existing *as a solid*. But this is not exactly what those to whom I refer mean. They mean that actual *existence* depends upon solidity, and that there can be no existent something manifesting itself in space as resistance unless it be in possession of this solidity.

It has been asserted that the idea of *vis inertiæ* is irreconcilable with the hypothesis that matter consists of centres of force. It is certainly true that, whatever views we may adopt regarding the physical constitution of matter, *vis inertiæ,* under some form

* Phil. Mag. for February 1844, and May 1846.

or other, must enter as an element into our theory. And it is also true that inertia, in the exact sense as understood by Newton, is not in all respects applicable to the theory of atoms being centres of force. But if we are allowed to differ from the ordinary views in regard to the constitution of matter, we are equally at liberty to differ in regard to our views of the nature of *vis inertiæ*.

When a body is in motion its moving force is in proportion to the square of its velocity. The question arises, why is the motion of the body an energy? How is it that force can be stored up in the body under the form of motion? The answer, according to the ordinary view, is, because the body possesses *vis inertiæ*. But this is simply saying in other words, an inert body in motion *is* a force or energy. According to the dynamical view the answer is equally the same; centres of force in motion are energies. In this respect *vis inertiæ* must be regarded as a quality of matter, whatever our views may be. *A priori* it is just as natural to suppose that the motion of the one should be an energy as the motion of the other. A body in motion *is* a force or energy; but we are in profound ignorance of the reason why it is so. It is no answer to say that a body in motion is a force, because it possesses *vis inertiæ*. This is merely asserting the fact, not giving the reason. We know from experience that a body possesses some unknown quality, by virtue of which it is, when in motion, an energy or force. Newton calls this quality *vis inertiæ*, because, according to his idea of matter, a body is inert, being altogether destitute of active qualities. The advocate of the dynamical views, who does not regard matter as wholly inert, may, if he chooses, in conformity to common usages, designate this unknown quality by the term *vis inertiæ*. The quality must have some name, and perhaps it is as well to abide by the old one. But if we imagine that when we assert that a body in motion is an energy because it possesses *vis inertiæ* we convey to the mind some idea *how* it happens that a moving body is such, we certainly deceive ourselves.

Our knowledge of *vis inertiæ* is exclusively derived from experience. No one could predict *à priori* that matter possesses *inertia*. The advocate of the old theory has therefore no warrant whatever to assert *à priori* that a centre of force in motion is not a force or energy by virtue of the motion. And if he has no warrant *à priori*, he has as little *à posteriori*; for how can he who maintains that *all* matter is essentially solid, prove experimentally that matter constituted of forces has no *vis inertiæ*?

Although we are unable in the present state of our knowledge to explain fully how it happens that when, for example, an atom A strikes a similar atom B at rest, it communicates to B its moving force, yet we believe that the dynamical theory will be found to penetrate deeper into the question than the old theory of inert solidity, as the following considerations may perhaps show.

If an atom A, perfectly elastic, moving with any given velocity, strikes a similar atom B at rest, it transfers its entire motion or force to B, and remains at rest itself. But no transference could possibly take place unless B offered resistance to A. Upon what principle, then, does B offer resistance to the advance of A? According to the ordinary view B is an inert solid, void of all power to offer any active resistance; but yet it does, nevertheless, offer resistance. According to the dynamical view, B is a point offering active resistance to every body which approaches within its sphere. When A reaches the place where resistance or repulsion commences, viz. the surface of B, then A meets with resistance as it advances into B and loses motion in consequence. But the motion thus lost by A is communicated to B. This transference goes on till both atoms have the same velocity. At this moment A has transferred to B the half of its moving force. But this condition of things cannot remain, for A has passed within the repulsive sphere of B (the sphere of its activity) and B within the repulsive sphere of A, and the consequence is, the two atoms must mutually repel each other; A will therefore still continue to push B forward. B, on the other hand, will continue to push A backwards until A is brought to rest; after this B will separate from A; but by this time B's velocity will be equal to that which A originally possessed.

Elasticity on the dynamical theory follows as a necessary consequence. But on the ordinary theory it is wholly inconceivable, if it be not contradictory. When A has communicated to B the half of its moving force, and the two atoms are moving forward with equal velocity, how, upon the ordinary theory, do they not continue to move side by side with equal velocity? How can B, an inert solid block, by means of *inertia,* without the exertion of any activity, begin now to act upon A so as to push it backwards and stop its motion?