The Inertia of Energy*

As Related to the Evolution of Matter

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UNTIL the last few years modern physics was based upon a fundamental dualism, that of matter and of energy. Between the properties of these two agents of all natural phenomena there was believed to be a radical antithesis—matter alone being endowed with mass, with weight in proportion, and with structure, and energy possessing neither inertia, weight, nor structure. Both are alike indestructible, upon which fact are based two distinct principles: the principle of the conservation of the mass and that of the conservation of energy.

The series of discoveries made during the last 20 years concur, if not in the rejection of this dualism, at least in the ruin of this antithesis; they oblige us to so assimilate matter and energy as to endow them with common properties. But the two terms of an antithesis may be assimilated in two very different fashions. We may reconcile the first term with the second and maintain the dematerialization of matter; or we may reconcile the second term with the first and maintain the materialization of energy.

Dr. Gustave Le Bon, in "The Evolution of Matter," has essayed the first reduction, by showing that matter disintegrates into electrons, which themselves are dissipated in the form of radiation in the ether; Einstein has essayed the second, by showing that the principle of relativity tends towards the endowment of energy with inertia. There result inevitable discordances between these two methods of procedure, but also remarkable concordances which it is interesting to set forth.

For convenience in our exposition of the subject let us enunciate the postulates of the dualist doctrine in the following manner, the last two postulates being the consequence of the first:

1. The presence of energy in matter does not increase its inertia.
2. The presence of kinetic energy in particular, *i. e.*, the state of movement of a body, does not increase its mass.
3. The absorption or emission of energy by radiation neither increases nor diminishes the mass of a body.

It results from these three propositions that the mass of a body is invariable, and that energy is lacking in inertia.

Let us bear in mind that mass can be defined in at least two distinct manners. It may be defined as the coefficient of inertia, by the quotient of the force and of the acceleration $M = \frac{F}{a}$; it may be defined as the coefficient of capacity of movement, called maupertuisian mass, as the quotient of the quantity of movement of a body $g = mv$ by the speed, *i. e.*, $M = \frac{g}{v}$. Later we shall have to recall this second definition of mass, which classic mechanics regards as equivalent to the first.

I

J. J. Thomson overthrew, in 1881, the first postulate of the dualist theory, by showing that *an electrified body, by reason of the electrostatic energy of its charge, possesses a supplementary inertia of electromagnetic origin.*

This results from the self-induction of currents of conduction, from the existence of currents of convection, and from the identity of these two kinds of currents with respect to the magnetic actions which they generate.

The self-induction of currents is a true electrical inertia which opposes itself to any change of intensity of currents, just as material inertia opposes itself to any change of speed of movable objects. Just as it is necessary to expend a certain amount of effort to put a body in motion, similarly it is necessary to expend a certain amount of work to establish a current; and just as a movable object when set in motion tends to preserve its rate of speed, in the same way a current once established tends to preserve its intensity.

The existence of currents of convection, predicted by Maxwell in virtue of the law which connects the variation, in time and in space, of the electric field and of the magnetic field, has been verified experimentally by Rowland. It consists in the fact that a charged particle in motion comports itself like an element of current, *i. e.*, it generates a magnetic field in which the circular lines of force are superposed on the radial lines of force of the electric field. A charged particle in motion, by reason of the current of convection which it generates, must possess a

self-induction, *i. e.*, an excess inertia, of electro magnetic origin, which will be added to its inertia proper and will increase its mass. Max Abraham and then Lorentz demonstrated, the first in virtue of the law of Maxwell, the second in virtue of the principle of relativity, that this supplementary inertia must increase with the speed and become infinite for the limited speed of light.

The fortunate parallelism which occurred at this period between the progress of theoretical and of experimental physics revealed in the cathodic emanation proceeding from Crookes tubes, and in the β rays proceeding from the atomic disintegration of radio-active bodies, electrified particles moving at speeds varying from 30,000 to 290,000 kilometers per second. An experimental verification of the laws of Max Abraham and of Lorentz became possible, which, undertaken by Kaufman and then by Bucherer revealed two things: the particles in question are elementary charges, without material support, of atoms of resinous electricity whose inertia is of electromagnetic origin solely; their inertia varies with the speed conformably to the law predicted by Lorentz. The following consequences ensue:

1. One form at least of energy, electric energy, is inert.
2. The presence of a certain quantity of electric energy in a body increases its mass;
3. This supplementary mass, of electromagnetic origin, varies in function of the speed.

If we accept the electronic theory of matter, according to which molecular structures are architectural edifices of electrons, we are led to the following generalizations, which are imposed as we see by the principle of relativity:

1. The mass of material bodies is of electromagnetic origin solely.
2. The mass of bodies varies in function of the speed.

II

It is not entirely this sort of consideration which has led Einstein to the idea of the inertia of energy. It is the principle of relativity, joined to the principle of the conservation of the quantity of movement in a closed system, or, what amounts to the same thing, the equality of action and reaction.

The principle of relativity springs from the checking of all attempts to demonstrate the absolute movement of a system by experiments made in the interior of that system. Classic mechanics has already admitted that mechanical phenomena, in a system animated by a uniform rectilinear movement, occur precisely as if the system were in repose.

An observer enclosed in the bullet of Jules Verne would be able to perceive the accelerations and rotations undergone by the bullet; but he could in no way become aware, by mechanical experiments, of his movement of uniform translation. This ceases to be true if he resorts to optical or electrical experiments. The electromagnetic theory of light assumes the intervention of a medium in repose, the ether, which transmits the transverse waves of light with a definite velocity, as air transmits waves of sound. In the case of a sonorous source the relative movement of the source with respect to the air can be measured without thereby revealing the absolute movement of the source with respect to the ether, since the air is entrained with the body. This ceases to be the case with the ether. The latter, if it exists, is immobile by virtue of the experiment of Fizeau so truly so that one might hope, by means of optical experiments in the interior of a system, to detect the absolute movement of a luminous source, connected with the system, with respect to the ether.

Experiments have been very numerous in this direction, in particular those of Michelson and Morley. They have all led to the same negative result: *given different groups of observers O and O' some of which have a uniform movement of translation with respect to the others, the physical laws are exactly the same for these different groups of observers.*

The preceding principle, called the principle of relativity, involves numerous consequences which revolutionize the classic ideas of time, space, causation and solid bodies. One of the most astonishing is the contraction of all bodies in the direction of their translation, in the ratio $\sqrt{1 - \frac{v^2}{V^2}}$, v designating their velocity, and V the velocity of light in vacuo.

The same principle requires, as Lorentz has demonstrated, not only that all bodies in movement, electrons or material systems, shall undergo this deformation, but

that their mass shall vary in function of speed as if it were of electromagnetic origin solely, *i. e.*, as if the electronic theory were true, in which case the preceding generalizations would be justified.

Of those consequences we will retain but a single expression: *absolute movement is a physical absurdity.*

The inertia of energy results, therefore, from the necessity of reconciling the pressure of radiation with the principle of relativity.

Maxwell, starting from the electromagnetic theory of light, and Bartoli, starting with the principles of thermodynamics, predicted theoretically, and Lebedef verified experimentally that all radiation exerts a pressure towards the rear upon the source of emission, and an impulsion forward upon the obstacle which absorbs it. This is what is termed the pressure of radiation.

The existence of this pressure leads us to believe in the inertia of energy, if we desire to preserve the principle of the conservation of the quantity of movement in a closed system, or the principle of action and reaction, of which it is a simple corollary, at the same time as the principle of relativity.

The principle of the equality of action and reaction declares that if a body A acts upon another body B, the body B reacts upon the body A, and that these two actions are constantly equal and opposite. It results from this, in the case of a closed system, that the total quantity of movement is conserved. If a body provokes, by an interior action, the appearance of a certain quantity of movement, counted positively, in acting on another body, it will undergo a repulsion on the part of the latter, and will consequently lose a quantity of movement which, because of the equality of action and reaction, will be equal to the first and in the contrary direction, so as to compensate it. The center of gravity of the system will remain immobile.

Let us consider, for example, a material system whose movements are due to interior action only, such as a firearm and its projectile.

When the shot is fired the gun undergoes a recoil, *i. e.*, it takes a certain quantity of movement which counted negatively represents a loss; the projectile is projected forward and acquires a quantity of movement which, counted positively, is equal to that lost by the gun.

There is a conservation at all times of the total quantity of movement of the system, and, consequently, fixity of its center of gravity. The conservation of the quantity of movement is only a natural consequence of the instantaneous equality of action and reaction: the gun recoils because, while acting upon the projectile the latter reacts equally upon it.

Let us consider now a material source which radiates dissymmetrically, in a single direction, like a lamp with a reflector or a Hertzian exciter in the center of a parabolic mirror. At the moment of emission the source recoils because of the pressure of radiation; there is a loss of a quantity of movement. If the radiation encounters an obstacle which absorbs it, it communicates to it an impulse, *i. e.*, a quantity of movement equal to that lost at the departure by the source. The action experienced by the obstacle will be equal therefore to the reaction undergone by the source.

Does this imply that the principle of the conservation of the quantity of movement, or of action and reaction, will be respected? Assuredly not, for this is not the case at first at each instant. There elapses a certain period of propagation between the time when the radiation is emitted and that when it is absorbed, during which the quantity of movement lost by the source and the reaction which is the cause of it remain without compensation. This compensation will never take place if the radiation is propagated infinitely without encountering matter which absorbs it. In such case there will be a definite loss of a quantity of movement, and the center of gravity of the system formed by the material source and the radiation will acquire an absolute movement, which is contrary to the principle of relativity.

If we desire to preserve this principle and likewise that of the conservation of the quantity of movement, it is necessary to assimilate the source—radiation system to the material system of the gun and its projectile; we must treat the radiation as a material projectile, *i. e.*, consider that it represents a certain quantity of movement equal to that lost by the source, so that the action experienced by the source shall be the natural effect of the action exerted upon it. In this case only, the center of gravity of the system will remain fixed, and the principle of relativity will be respected.

*This note has been specially prepared as an appendix to *The Evolution of Matter* by Dr. Gustave Le Bon.
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But quantity of movement implies, by definition, that a mass is in motion, by virtue of the vectorial relation $g = mv$. The projectile in its movement carries away a part of the initial mass of the loaded fire-arm, which finds itself diminished by an equal amount. It is for this reason that there is an instantaneous equality of action and reaction, conservation of the quantity of movement, and immobility of the center of gravity of the system. If, therefore, a radiation is a vehicle of quantity of movement it must necessarily be that it carries away with it a part of the initial mass of the radiant material source.

To measure this mass it suffices to estimate the quantity of movement which a radiation represents. It should be equal to "the pressure of radiation" exerted upon the source which emits it. The value of this pressure $= \frac{E}{V}$, in which E represents the density of the radiating energy emitted in the unit of time, and V the velocity of the light. The quantity of movement, therefore, has for its value:

$$(1) \quad g = \frac{E}{V}$$

The Maupertuisian mass being equal to $M = \frac{g}{V}$, we get for this mass, by replacing g by its value in the preceding formula:

$$(2) \quad m = \frac{E}{V^2}$$

the mass of radiant energy is equal to the quotient of the energy by the square of the velocity of light. The radiation, like all resinous electricity, possesses an electro magnetic inertia.

Since all forms of energy can be converted into radiation we can generalize the preceding result in the following manner:

Every form of energy, whatever it may be, has a coefficient of inertia, a mass equal to $\frac{E}{V^2}$. If a body radiates energy the radiation emitted carries away with it a part of its initial mass, or $\frac{\Delta E}{V^2}$, and when an obstacle absorbs this radiation, its mass is increased by the entire Maupertuisian mass of the absorbed radiation $\frac{\Delta E}{V^2}$. This leads us therefore, to the following proposition:

The mass of a body is not invariable; it diminishes or increases according to whether the body emits or absorbs energy, in the ratio $\Delta m = \frac{\Delta E}{V^2}$. The last postulate of the dualist theory is therefore, proved to be faulty.

The mass of bodies being no longer a constant quantity, the principle of the conservation of the mass of material bodies ceases to be true of itself.

There remains only the principle of the conservation of energy. In an isolated system, whose different parts exchange energy between themselves, the individual masses of the bodies present are not conserved; that which is conserved is the total inertia of the system, and consequently its energy. According to the relation (2), if we take the velocity of light as the fundamental unit, we see, in effect, that the mass of a body is equal to its total energy, or again that the mass of a body measures its internal energy.

III

A first consequence of the inertia of energy is the possibility of calculating the internal energy of bodies. For this purpose it suffices to apply the formula $E = mV^2$, which we can immediately derive from (2). We find that a gram of matter, taken at rest and at the temperature of absolute zero, corresponds to the presence of an internal energy equal to 9×10^{-20} ergs, i. e., equivalent to the heat furnished by the combustion of 3×10^9 grams, or three million kilograms of coal. It is interesting to compare this figure with that found by Dr. Gustave Le Bon, starting with the kinetic hypotheses on the constitution of the atom. This author estimates the energy condensed in a gram of matter at 2,830,000 kilograms of coal.

This colossal internal energy can only be an intra-atomic energy. In effect, at the absolute zero, the molecules are as if ankylosed by freezing, and, moreover, the physical molecular forces and the chemical atomic forces set in operation only a quantity of energy which is very small compared to this colossal reserve of latent energy, as is easily accounted for.

1. *Variation of mass with temperature.*—The same portion of matter, taken at two different degrees, can pass from one to the other by emission or absorption of radiant heat. We can calculate the variation of mass which results therefrom by dividing by V^2 the quantity of heat exchanged with the exterior. To comprehend the degree of size of the predicted effect let us consider water, whose calorific capacity is particularly high. A mass of water having at 0° an inertia equal to one gram

will have a greater inertia at 100° . The difference will be obtained by dividing the absorbed heat, 100 calories gram-degree or 4.17×10^9 ergs, by V^2 , equal in the same system of units to 9×10^{20} , which gives about 5×10^{-12} , that is to say, a practically insensible variation.

This example proves, nevertheless, that we can no longer confound the idea of mass with that of quantity of matter, as did Newton. Two masses of water of equal inertia, taken one at 100° and the other at 0° , do not contain the same quantity of matter, the same number of molecules, since they cease to be equal when we bring them to the same temperature.

2. *Variation of mass in chemical reactions.*—Chemical reactions being all either exothermic or endothermic, the sum of the masses of the combined elements does not remain constant, by virtue of the relation $\Delta E = V^2 \Delta m$.

Let us take, for example, the formation of water from its elements in the gaseous state. The combination of two grams of hydrogen and 16 grams of oxygen liberates 69,000 calories gram-degree, equivalent to about 3×10^{12} ergs. Therefore we should not obtain 18 grams as the result of the combination, for the heat disengaged in the form of radiation involves a loss of mass equal to $\frac{1}{2} \times 10^8$ grams, or a difference of five billionths between the mass of the exploding gas and that of the water which it can form at the same temperature.

3. *Variation of mass in radio-active transformations.*—The same thing will hold in radio-active transformations. The initial mass of one of these bodies and the total mass of its products of disintegration at the end of a certain time, will not be equivalent, the transformation being accompanied by radiation. We know that a gram of metallic radium sets free 130 calories per hour. At the same time that it is being transformed into radium D and into helium, through the successive forms of emanation, of radium A, B, C. Taking into account that the average life of an atom of radium is 2,600 years, we can calculate that the total transformation of one gram of radium into helium and into radium D will liberate energy equal to 1.1×10^{17} ergs. This emission of energy will correspond to a difference between the primitive mass of the radium and the total mass of the radium D and the helium equal per gram to $\Delta m = \frac{1.1 \times 10^{17}}{9 \times 10^{20}} = 1.2 \times 10^{-4}$. The disintegration of radium into helium and radium D represents only one stage of the transformations which start with uranium to end in helium and in lead. The complete disintegration of a given quantity of uranium into helium and lead would represent a loss of mass greater than one ten thousandth of that of the primitive uranium.

The fraction of the mass which is thus transformed into radiant energy is of much greater size than is the case in chemical reactions. It is to be presumed that it proceeds from the latent energy of the uranium, that is, from its intra-atomic energy. If we could succeed in establishing exactly, up to sizes of the degree of 10^{-4} , the balance of the masses in the case of radio-active transformations, it would be possible to verify the identity of the mass and of the energy.

To resume, energy is inert, and the mass of a body is equal to its internal energy, which it enables us to measure. This internal energy represents, at the absolute zero, a colossal accumulation of intra-atomic energy. According to whether a body acquires energy or gives it up, its mass increases or diminishes. It is greater for the same body when in motion than when at rest, when hot than when cold, when electrified than when discharged; it varies in chemical reactions, and even more perceptibly in radio-active transformations.

The mass of a body can transform itself into radiant energy and vice versa, so that mass and energy become two equivalent magnitudes convertible one into the other, like mechanical labor and heat. The principle of the conservation of the mass is included in the more general and only rigorous principle of the conservation of energy. It is very impressive to compare these conclusions with those which Dr. Gustave Le Bon has derived from a very different order of considerations. Their concordance assumes the significance of a guarantee of objectivity.

The Formation of Diamonds

For some years nothing seems to have been written on artificial diamonds, and the practically negative results of the new experiments of Professor Ruff, extending over three years, will hardly induce others to take up this study. The systematic research of Ruff (*Zeitschrift für Anorganische Chemie*, pages 73 to 105, May 15, 1917) was undertaken with the object of testing all the reactions likely to lead to a deposition of carbon, and he tried in particular, also, whether small real diamonds would grow under his experimental conditions. To bar the possibility of mistakes in view of the fact that any resulting growth would probably be minute, he purified these diamonds first with hydrofluoric, nitric and sul-

phuric acids, potassium nitrate, and, finally, with chlorine at 1,000 deg. C. He confirmed the statement of previous experimenters that small crystals of carborundum and alumina, even of quartz, had apparently been mistaken for diamonds, and his own artificial crystals, which fluoresced like diamonds in ultraviolet light and under α -radiation, were too small to admit of any conclusive analysis. In the first series of experiments he submitted gases (coal gas, acetylene, carbon tetrachloride, carbon monoxide, methane, etc.), alone or mixed with vapors (iodoform, benzene, carbon disulphide, etc.), to temperatures ranging from 200 deg. C. up to 3,500 deg. for 14 days, without obtaining more than an amorphous or graphite growth, except in one case. The carbon electrode arc of 5,000 volts alternating and 0.5 ampere, burning in liquid air for a very short time, yielded some very small crystals; arcs burning in flowing water and singing arcs did not give any distinct result, though the hard mass forming at sharp points left no residue when burnt. Experiments with liquids, heated up to 30 days, of paraffin, wax, graphite acid, pitch, diphenylamine, etc., to which sometimes various metals (mercury, silver, silicon, aluminium, sodium, etc.) were added, were resultless. Quenching fused metals saturated with carbon at 1,350 deg. C. (iron alone or alloyed with high percentages of silicon, titanium, vanadium, tungsten; also cobalt, nickel or manganese) yielded very small diamonds such as Moissan obtained; but an alloy of low melting-point (850 deg. C.), consisting of 100 parts by weight of iron, 100 parts of antimony, and 60 parts to 75 parts of manganese, yielded nothing, not even when a small diamond was embedded in the alloy, which was heated in a carbon arc. Fused silicates, etc., were no good either as solvents for carbon; this is particularly interesting, because Ruff especially tried silicates of the composition of the blue ground of Kimberley, in which diamonds occur. Nor did Ruff obtain any diamond-like crystals by electrolyzing at 2,200 deg. fused calcium carbide, with which method Boismenu claimed to have been successful a few years ago. Finally, Ruff made experiments with a steel bomb, similar to that which Johnston and Adams had used in 1911 at Washington, at hydraulic pressures of 3,000 atmospheres, to heat liquids (oils, etc.) and gases (CO) for days and to produce a carbon arc in gas or in water. A carbon rod of 1.5 mm. diameter, heated in water by currents of 35 amperes at 80 volts, burned through in 5 seconds, but the drop of fused carbon merely solidified to a hard graphite.—*Engineering*.

Pacifying the Jack Rabbit

For the past eight months we have succeeded in keeping the western jack rabbit on exhibition. All previous attempts with this excessively nervous animal have been failures. New arrivals frantically try to escape, and become so frenzied they run blindly against the cage-work and suffer fatal injuries. A specimen which arrived last summer was given a big box in which to hide, and gradually we made friends with him by enticing him out with food. When he began investigating his yard without symptoms of panic, another specimen was ordered from the West. The second specimen at once gathered confidence from the calm demeanor of the first, and the pair now live happily. Visitors are at once interested in these animals, owing to the rabbits' grotesque ears, which are of enormous size, and according to the mood of the animal are directed at eccentric angles. This successful experiment of maintaining the species has led us to consider plans for a colony of jack rabbits. The idea is to exhibit them in a roomy enclosure like that of the prairie dogs.

—*New York Zoological Society Bulletin*.

Fluorescent Bacteria

The existence of fluorescent bacteria has been recorded, though the coloring matter produced by them is insoluble in ether. Further, E. Rostrup has observed that *Agaricus (Pleurotus) scrotinus*, Schrad., imparts a peculiar fluorescence to spirits of wine, and A. Ling found that a *Torula* occurring in ale gave to it a greenish fluorescence. Now Prof. A. Klocker (*Comptes rendus des travaux du Laboratoire de Carlsberg*, vol. ii., part 6) describes the production of a faint greenish fluorescence when *Aspergillus glaucus* is grown in a medium containing sugar, and the isolation of the coloring principle. When the medium (e.g. beer wort) in which *A. glaucus* has been grown is shaken with ether, the latter acquires a faint yellowish color, and in thick layers a blue fluorescence. If the ethereal solution is shaken with ammonia this exhibits a very marked green fluorescence, whilst if soda be used the fluorescence is reddish-brown. On evaporation the ethereal solution leaves a yellow residue having the properties described.