LIV. *On the Identity of Energy: in connection with* Mr. Poynting's *Paper on the Transfer of Energy in an Electromagnetic Field; and on the two Fundamental Forms of Energy.* *By* Oliver Lodge, *D.Sc.**

It is well known that Prof. Poynting has communicated to the Royal Society a most admirable and important paper, "On the Transfer of Energy in the Electromagnetic Field" †; a paper which cannot but exert a distinct influence on all future writings treating of electric currents.

In that paper he introduces the idea of continuity in the existence of energy—a natural though not a necessary consequence of its conservation; so that, whenever energy is transferred from one place to another at a distance, it is not to be regarded as destroyed at one place and recreated at another, but it is to be regarded as transferred, just as so much matter would have to be transferred; and accordingly we may seek for it in the intervening space, and may study the paths by which it travels.

This notion is, I say, an extension of the principle of the conservation of energy. The conservation of energy was satisfied by the *total quantity* remaining unaltered; there was no individuality about it: one form might die out, provided another form simultaneously appeared elsewhere in equal quantity. On the new plan we may label a bit of energy and trace its motion and change of form, just as we may ticket a piece of matter so as to identify it in other places under other conditions; and the route of the energy may be discussed with the same certainty that its existence was continuous as would be felt in discussing the route of some lost luggage which has turned up at a distant station in however battered and transformed a condition.

In this new form the doctrine of the conservation of energy is really much simpler and more satisfactory than in its old form; and the doctrine may be proved rigidly and instantaneously from two very simple premises, viz. Newton's law of motion on the one hand, and the denial of action at a distance on the other; as I endeavoured in this Magazine some time ago to show‡, and will now repeat.

I speak of Newton's *law* of motion because I believe it will be admitted that Newton's three laws of motion, in so far as

* Communicated by the Author.

† Poynting, Phil. Trans. ii. 1884, p. 343.

‡ Phil. Mag. January 1881, p. 36; and June 1881, p. 531. Also 'Elementary Mechanics' (Chambers), § 80.

they are more than definitions, are really three very important aspects of one law*. They may be regarded as (1) a definition of time, (2) a definition of force, (3) a statement of a law of Nature.

The law of Nature they embody is capable of various modes of expression, such as these (in brief):—

Change of Momentum = Impulse.

$$\textit{Resultant force} = \frac{d(mv)}{dt}.$$

Action + Reaction = 0.

Force is always one component of a stress.

The last form is perhaps as convenient as any for our present purpose, and is our first lemma.

To deny action at a distance is easy; we have only to say, "If a stress exist between two bodies they must be in contact." This constitutes a second lemma.

We then only further require the definition of work and energy; for instance, these:—A body does work when it exerts force through a distance; the measure of work being $\int F ds$. Energy is that which a body loses when it does work; and it is to be measured as numerically equal to the work done. [The repetition with mere change of sign, about gain of energy when negative work is done by a body, or positive work done *upon* it, may be understood.]

Now at once follows, simply and rigorously, the law of the conservation of energy; and not only conservation, but conservation in the new form, viz. the *identification* of energy; thus: If A does work on B it exerts force on it through a certain distance; but (Newton's law) B exerts an equal opposite force, and (being in contact) through exactly the same distance; hence B does an equal opposite amount of work, or gains the energy which A loses. The stress between A and B is the means of transferring energy from A to B, directly motion takes place in the sense AB. And the energy cannot *jump* from A to B, it is tranferred across their point of contact, and by hypothesis their "contact" is absolute: there is no intervening gap, microscopic, molecular, or otherwise. The energy may be watched at every instant. Its existence is continuous; it possesses identity.

It is no use objecting that two pieces of "matter" are never in contact—nobody said they were. If they are not, and it seems quite certain that they are not, then evidently one

* For argument in support of this view, see 'The Engineer,' 1885, March 20, April 24, May 15.

piece of "matter" cannot act immediately on another piece. A and B therefore are not two pieces of "matter" in the ordinary sense. A may be a molecule of matter, M may be the nearest molecule to it, and energy may be transferred from A to M, but not directly; A cannot act on M, cannot do work on it, because of the intervening gap. A can act on B, transferring its energy to B, B can act on C, C on D, and so on, handing on the energy to L, which is in contact with, and can act on, M, doing work on it and giving up to it the energy lost by A.

What B, C, D, ... L are, I do not presume to say; but of course one supposes them to be successive portions of the perfectly continuous space-filling medium Æther.

Relation between Potential and Kinetic Energy, from the contact point of view. Reason of the two forms; and Transformation into one another.

In the older and more hazy view of conservation of energy the idea of "potential energy" has always been felt to be a difficulty. It was easy enough to take account of it in the formulæ, but it was not easy or possible always to form a clear and consistent mental image of what was physically meant by it.

A stone is raised, it gains potential energy; but how does the stone "up" differ from the stone "down"?, and how can an inert and quiet stone be said to possess energy? Well, then, the stone hasn't the energy but the earth has, or rather "the system of earth and stone possesses energy in virtue of its configuration." True, but foggy. The usual ideas and language current about potential energy are proper to notions of action at a distance. When universal contact action is admitted, the haze disappears*; the energy is seen to be possessed, not by stone or by earth or by both of them, but by the medium which surrounds both and presses them together; and the following statement may be made.

Energy has two fundamental forms because work has two factors, force and motion, F, *s*.

Work cannot be done except by a body exerting force *and* in motion. Force without motion is no good. Motion without force is no good. Either factor separately may be energy, but it is not work.

* It is by no means intended that the natures of gravitation, elasticity, cohesion, &c. become clear. What is meant is, that the *seat* of the energy is clearly recognized: the *reason* of the stress recognizable in the medium is a much higher and more difficult problem.

The two forms of energy correspond to the factors in the product work *.

"Potential" energy correspond to F.

"Kinetic" energy correspond to *s*.

But is this quite true and satisfactory? A strained bow is exerting force and possesses energy. A pillar supporting a roof is exerting force, but possesses no energy. What is the difference between the two cases? It is evident that something more is needed than mere force.

The difference of course is that the bow can recoil, it has a *range* or distance through which it will continue to exert a force: not the original force, but still some force. The pillar is exerting a great force but it has no recoil in it; if released it would at once cease to exert any force; consequently its energy is minute.

Thus, then, for a body to possess potential energy we must have two things—the exertion of a force, together with a guarantee that that force shall be exerted over a certain distance; *i. e.* a continuance of the force even after motion is permitted.

And this is quite analogous to what may be said of the other form of energy. "A body in motion possesses energy;" but is it so necessarily? Cannot a body in motion be conceived as possessing no energy? Suppose it stops the instant you give it work to do—the instant you make it exert force. It is evident you must have not merely motion, you must have a guarantee of *persistence* of motion, the body must possess inertia; the motion must continue over a certain range even against resistance. Hence we may exhibit the relation between the two forms thus:—

Kinetic energy corresponds to motion combined with inertia, so that the motion shall continue even against some force; and

Potential energy corresponds to force combined with elasticity (or something like it), so that the force shall continue even though motion be permitted.

Both forms of energy are *potential work*, but, *qua* energy, one is as real and actual as the other. Each has a factor missing, which if supplied, work will at once be done. Kinetic energy requires the Force factor to do work. Potential energy requires the Motion factor to do work.

An important thing is now evident moreover, a thing which I have never seen accepted, though it has been pre-

* *Cf.* Lodge on "Forms of Energy," Phil. Mag. October 1879, p. 281, and June 1881, p. 531. Also 'Elementary Mechanics' (Chambers), § 84.

viously pointed out*. The statement is in two parts:—(1) *Energy cannot be transferred without being transformed*; and (2) *it always transforms itself from Kinetic to Potential, or vice versâ.*

When A does work on B energy is transferred from A to B; and I say that if the energy which A lost was kinetic, then what B gains is potential; if, on the other hand, A loses potential, then B gains kinetic.

I may make a converse statement, viz. that *energy cannot be transformed without being transferred*; cannot take on a different form without being at the same time shifted to a different body. So that the common mode of treating a falling weight, saying that its energy gradually transforms itself from potential to kinetic but remains in the stone all the time, is, strictly speaking, nonsense. The fact is the stone never had any potential energy, no rigid body can have any; the gravitation medium had it however, and kept on transferring it to the stone all the time it was descending.

The above statement, that transformation of energy necessarily goes on from potential to kinetic or *vice versâ* at every act of transfer, almost proves itself. It follows from the following facts:—When a body possessing potential energy does work, its "range" necessarily diminishes, while the motion of the body on which the work is done increases. On the other hand, when a moving body does work its motion diminishes, and the body which resists the motion, since it yields over a certain distance, gains potential energy. For the first case think of a catapult, bow and arrow, or air-gun. For the second case think of a bullet fired against a spring and caught by it.

These examples are favourable and easy, but any others will serve equally well to illustrate the matter if regarded from the right point of view. Thus a bullet fired upwards gradually transfers its undissipated energy to the gravitation medium, transforming it at the same time into potential. As soon as the highest point is reached, the gravitation medium proceeds to re-transfer and transform it. A pendulum exhibits the alternation of energy from the kinetic to the potential form and the accompanying transfer from matter to medium, at every half-swing. Any vibrating body does the same; but in considering a strained spring we must remember that the energy resides not in the spring as a whole but in its elementary parts. The strain resides not even in the molecules themselves, perhaps, but in something between those molecules (for by hypothesis molecules are incapable of exerting *direct* force on one another, not being in contact). The medium is exerting the force, and will continue to exert it over a certain range, hence it possesses the potential energy; when released it will do work and transfer its energy to the steel, in the kinetic form. If the spring overshoots its mean position, the energy is re-transferred and transformed. A perfectly elastic bounding ball has all its energy transformed into potential, at the middle of every period of contact with the obstacle from which it rebounds.

* Phil. Mag. October 1879, p. 281, sect. 11, and June 1881, p. 532; And 'Elementary Mechanics,' § 85.

One case possesses perhaps a little more difficulty, viz. the case of a bullet fired into dough—when the body exhibits no recoil: how can the energy of the bullet be said to be transformed into potential now? Only by remembering that heat-motion is a vibration of some kind, and that when a vibration is excited by a blow or by friction, *strain* is the effect first produced, and afterwards the recoil. Think, for instance, of exciting a tuning-fork or a string by bowing or striking it.

Alternations from kinetic to potential may be rapid in some cases, slow in others: no matter; all I have stated is that change of form is necessary and universal whenever energy is transferred, *i. e.* whenever any kind of activity is exhibited by any known kind of material existence.

University College, Liverpool,
May 16, 1885.

LV. *On the Paths of Electric Energy in Voltaic Circuits. Appendix to Paper on the Seat of the Electromotive Forces in the Voltaic Cell.* By Prof. OLIVER LODGE*.

[Plates IV. & V.]

THE main conclusions to which I have been led with regard to the potentials of metals and the seat of E.M.F. may be very briefly stated thus:—

(1) A metal is not in general at the same potential as the air in contact with it; the difference of potential (or contact-force) between any given clean metal and air being calculable, at least approximately, from thermo-chemical data, though there is no known way of experimentally observing it.

(2) Putting two metals into contact equalizes their poten-

* Communicated by the Author. For the sake of completeness it may be convenient here to mention that a report of a discussion on Seat of E.M.F., at Montreal (Brit. Assoc., Sect. A), is published in the 'Electrical Review' for Nov. 22, 1884, and that a more elaborate discussion on the same subject, by the Society of Telegraph Engineers and Electricians, will be reported in their volume of 'Proceedings' next issued after the present date.