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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

* 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.

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

$$\textit{Action} + \textit{Reaction} = 0.$$

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.