probably be one of the last to deny the possibility of a totally different imagery by which the phenomena might be represented.[1]

To Professor Faraday.

129 Union Street,
Aberdeen, 9th November 1857.

Dear Sir—I have to acknowledge receipt of your papers on the Relations of Gold to Light, and on the Conservation of Force. Last spring you were so kind as to send me a copy of the latter paper, and to ask what I thought of it.

That question silenced me at that time, but I have since heard and read various opinions on the subject, which render it both easy and right for me to say what I think. And first I pass over some who have never understood the known doctrine of conservation of force, and who suppose it to have something to do with the equality of action and reaction.

Now, first, I am sorry that we do not keep our words for distinct things more distinct, and speak of the "Conservation of Work or of Energy" as applied to the relations between the amount of "vis viva" and of "tension" in the world; and of the "Duality of Force" as referring to the equality of action and reaction.

Energy is the power a thing has of doing work arising either from its own motion or from the "tension" subsisting between it and other things.

Force is the tendency of a body to pass from one place to another, and depends upon the amount of change of "tension" which that passage would produce.

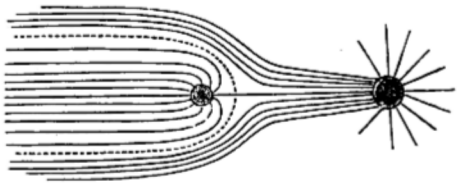
Now, as far as I know, you are the first person in whom the idea of bodies acting at a distance by throwing the surrounding medium into a state of constraint has arisen, as a principle to be actually believed in. We have had streams of hooks and eyes flying around magnets, and even pictures of them so beset;

[1] For confirmation of this, see Maxwell's (fragmentary) preface to the smaller treatise on electricity, published posthumously in 1881; especially these words: "In the larger treatise I sometimes made use of methods which I do not think the best in themselves, but without which the student cannot follow the investigations of the founders of the Mathematical Theory of Electricity. I have since become aware of the superiority of methods akin to those of Faraday, and have therefore adopted them from the first."

but nothing is clearer than your descriptions of all sources of force keeping up a state of energy in all that surrounds them, which state by its increase or diminution measures the work done by any change in the system. You seem to see the lines of force curving round obstacles and driving plump at conductors, and swerving towards certain directions in crystals, and carrying with them everywhere the same amount of attractive power, spread wider or denser as the lines widen or contract.

You have also seen that the great mystery is, not how like bodies repel and unlike attract, but how like bodies attract (by gravi[ta]tion). But if you can get over that difficulty, either by making gravity the residual of the two electricities or by simply admitting it, then your lines of force can "weave a web across the sky," and lead the stars in their courses without any necessarily immediate connection with the objects of their attraction.

The lines of Force from the Sun spread out from him, and when they come near a planet *curve out from it*, so that every planet diverts a number depending on its mass from their course, and substitutes a system of its own so as to become something like a comet, *if lines of force were visible.*



The lines of the planet are separated from those of the Sun by the dotted line. Now conceive every one of these lines (which never interfere but proceed from sun and planet to infinity) to have a *pushing* force instead of a *pulling* one, and then sun and planet will be pushed together with a force which comes out as it ought, proportional to the product of the masses and the inverse square of the distance.

The difference between this case and that of the dipolar forces is, that instead of each body catching the lines of force from the rest, all the lines keep as clear of other bodies as they can, and go off to the infinite sphere against which I have supposed them to push.

Here then we have conservation of energy (actual and potential), as every student of dynamics learns, and besides this we have conservation of "lines of force" as to their *number* and total strength, for *every* body always sends out a number proportioned to its own mass, and the pushing effect of each is the same.

All that is altered when bodies approach is the *direction* in which these lines push. When the bodies are distant the distribution of lines near each is little disturbed. When they approach, the lines march round from between them, and come to push behind each, so that their resultant action is to bring the bodies together with a *resultant* force increasing as they approach.

Now the mode of looking at Nature, which belongs to those who can see the lines of force, deals very little with "resultant forces," but with a network of lines of action of which these are the final results, so that I, for my part, can not realise your dissatisfaction with the law of gravitation, provided you conceive it according to your own principles. It may seem very different when stated by the believers in "forces at a distance," but there can be only differences in form and conception, not in quantity or mechanical effect, between them and those who trace force by its lines.

But when we face the great questions about gravitation—Does it require time? Is it polar to the "outside of the universe" or to anything? Has it any reference to electricity? or does it stand on the very foundation of matter, mass or inertia? —then we feel the need of tests, whether they be comets or nebulæ, or laboratory experiments, or bold questions as to the truth of received opinions.

I have now merely tried to show you why I do not think gravitation a dangerous subject to apply your methods to, and that it may be possible to throw light on it also by the *embodiment* of the same ideas, which are expressed *mathematically* in the functions of Laplace and of Sir W. R. Hamilton in Planetary Theory.

But there are questions relating to the connection between magneto-electricity and certain mechanical effects which seems to me opening up quite a new road to the establishment of principles in electricity, and a possible conformation of the physical nature of magnetic lines of force. Professor W. Thomson seems to have some new lights on this subject.—Yours sincerely,

JAMES CLERK MAXWELL.