[From the *Philosophical Magazine*, Vol. XXXII. p. 343, May, 1848.]

On the Constitution of the Luminiferous Ether.

The phenomenon of aberration may be reconciled with the undulatory theory of light, as I have already shown (*Phil. Mag.*, Vol. XXVII. p. 9*), without making the violent supposition that the ether passes freely through the earth in its motion round the sun, but supposing, on the contrary, that the ether close to the surface of the earth is at rest relatively to the earth. This explanation requires us to suppose the motion of the ether to be such, that the expression usually denoted by $udx + vdy + wdz$ is an exact differential. It becomes an interesting question to inquire on what physical properties of the ether this sort of motion can be explained. Is it sufficient to consider the ether as an ordinary fluid, or must we have recourse to some property which does not exist in ordinary fluids, or, to speak more correctly, the existence of which has not been made manifest in such fluids by any phenomenon hitherto observed? I have already attempted to offer an explanation on the latter supposition (*Phil. Mag.*, Vol. XXIX. p. 6†).

In my paper last referred to, I have expressed my belief that the motion for which $udx +$ &c. is an exact differential, which would take place if the ether were like an ordinary fluid, would be unstable; I now propose to prove the same mathematically, though by an indirect method.

Even if we supposed light to arise from vibrations of the ether accompanied by condensations and rarefactions, analogous to the vibrations of the air in the case of sound, since such vibrations would be propagated with about 10,000 times the velocity of the earth,

* *Ante*, Vol. I. p. 134.

† *Ante*, Vol. I. p. 153.

we might without sensible error neglect the condensation of the ether in the motion which we are considering. Suppose, then, a sphere to be moving uniformly in a homogeneous incompressible fluid, the motion being such that the square of the velocity may be neglected. There are many obvious phenomena which clearly point out the existence of a tangential force in fluids in motion, analogous in many respects to friction in the case of solids. When this force is taken into account, the equations of motions become (*Cambridge Philosophical Transactions,* Vol. VIII. p. 297*)

$$\frac{dp}{dx} = -\rho\frac{du}{dt} + \mu\left(\frac{d^2u}{dx^2} + \frac{d^2u}{dy^2} + \frac{d^2u}{dz^2}\right) \ldots\ldots\ldots\ldots\ldots (1),$$

with similar equations for y and z. In these equations the square of the velocity is omitted, according to the supposition made above, ρ is considered constant, and the fluid is supposed not to be acted on by external forces. We have also the equation of continuity

$$\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2),$$

and the conditions, (1) that the fluid at the surface of the sphere shall be at rest relatively to the surface, (2) that the velocity shall vanish at an infinite distance.

For my present purpose it is not requisite that the equations such as (1) should be known to be true experimentally; if they were even known to be false they would be sufficient, for they may be conceived to be true without mathematical absurdity. My argument is this. If the motion for which $udx + \ldots$ is an exact differential, which would be obtained from the common equations, were stable, the motion which would be obtained from equations (1) would approach indefinitely, as μ vanished, to one for which $udx + \ldots$ was an exact differential, and therefore, for anything proved to the contrary, the latter motion might be stable; but if, on the contrary, the motion obtained from (1) should turn out totally different from one for which $udx + \ldots$ is an exact differential, the latter kind of motion must necessarily be unstable.

Conceive a velocity equal and opposite to that of the sphere impressed both on the sphere and on the fluid. It is easy to prove

* *Ante*, Vol. I. p. 93.

that $udx + \dots$ will or will not be an exact differential after the velocity is impressed, according as it was or was not such before. The sphere is thus reduced to rest, and the problem becomes one of steady motion. The solution which I am about to give is extracted from some researches in which I am engaged, but which are not at present published. It would occupy far too much room in this Magazine to enter into the mode of obtaining the solution: but this is not necessary; for it will probably be allowed that there is but one solution of the equations in the case proposed, as indeed readily follows from physical considerations, so that it will be sufficient to give the result, which may be verified by differentiation.

Let the centre of the sphere be taken for origin; let the direction of the real motion of the sphere make with the axes angles whose cosines are l, m, n, and let ν be the real velocity of the sphere; so that when the problem is reduced to one of steady motion, the fluid at a distance from the sphere is moving in the opposite direction with a velocity ν. Let a be the sphere's radius: then we have to satisfy the general equations (1) and (2) with the particular conditions

$$u = 0, \quad v = 0, \quad w = 0, \text{ when } r = a \dots\dots\dots\dots (3);$$

$$u = -l\nu, \quad v = -m\nu, \quad w = -n\nu, \text{ when } r = \infty \dots\dots\dots (4),$$

r being the distance of the point considered from the centre of the sphere. It will be found that all the equations are satisfied by the following values,

$$p = \Pi + \frac{3}{2}\mu\nu\frac{a}{r^3}(lx + my + nz),$$

$$u = \frac{3}{4}\nu\left(\frac{a}{r^3} - \frac{a^3}{r^5}\right)x(lx + my + nz) + l\nu\left(\frac{1}{4}\frac{a^3}{r^3} + \frac{3}{4}\frac{a}{r} - 1\right),$$

with symmetrical expressions for v and w. Π is here an arbitrary constant, which evidently expresses the value of p at an infinite distance. Now the motion defined by the above expressions does not tend, as μ vanishes, to become one for which $udx + \dots$ is an exact differential, and therefore the motion which would be obtained by supposing $udx + \dots$ an exact differential, and applying to the ether the common equations of hydrodynamics, would be unstable. The proof supposes the motion in question to be steady; but such it may be proved to be, if the velocity of the earth be regarded as uniform, and an equal and opposite velocity be conceived impressed both on the earth and on the ether. Hence the stars would appear to be displaced in a manner different from that expressed by the well-known law of aberration.

When, however, we take account of a tangential force in the ether, depending, not on relative velocities, or at least not on relative velocities only, but on relative displacements, it then becomes possible, as I have shewn (*Phil. Mag.*, Vol. XXIX. p. 6), to explain not only the perfect regularity of the motion, but also the circumstance that $udx + \ldots$ is an exact differential, at least for the ether which occupies free space; for as regards the motion of the ether which penetrates the air, whether about the limits of the atmosphere or elsewhere, I do not think it prudent, in the present state of our knowledge, to enter into speculation; I prefer resting in the supposition that $udx + \ldots$ *is* an exact differential. According to this explanation, any nascent irregularity of motion, any nascent deviation from the motion for which $udx + \ldots$ is an exact differential, is carried off into space, with the velocity of light, by transversal vibrations, which as such are identical in their physical nature with light, but which do not necessarily produce the sensation of light, either because they are too feeble, as they probably would be, or because their lengths of wave, if the vibrations take place in regular series, fall beyond the limits of the visible spectrum, or because they are discontinuous, and the sensation of light may require the succession of a number of similar vibrations. It is certainly curious that the astronomical phenomenon of the aberration of light should afford an argument in support of the theory of transversal vibrations.

Undoubtedly it does violence to the ideas that we should have been likely to form *à priori* of the nature of the ether, to assert that it must be regarded as an elastic solid in treating of the vibrations of light. When, however, we consider the wonderful simplicity of the explanations of the phenomena of polarization when we adopt the theory of transversal vibrations, and the difficulty, which to me at least appears quite insurmountable, of explaining these phenomena by any vibrations due to the condensation and rarefaction of an elastic fluid such as air, it seems reasonable to suspend our judgement, and be content to learn from phenomena the existence of forces which we should not beforehand have expected. The explanations which I had in view are those which belong to the geometrical part of the theory; but the deduction, from dynamical calculations, of the laws which in the geometrical theory take the place of observed facts must not be overlooked, although here the evidence is of a much more complicated character.

The following illustration is advanced, not so much as explaining the real nature of the ether, as for the sake of offering a plausible mode of conceiving how the apparently opposite properties of solidity and fluidity which we must attribute to the ether may be reconciled.

Suppose a small quantity of glue dissolved in a little water, so as to form a stiff jelly. This jelly forms in fact an elastic solid: it may be constrained, and it will resist constraint, and return to its original form when the constraining force is removed, by virtue of its elasticity; but if we constrain it too far it will break. Suppose now the quantity of water in which the glue is dissolved to be doubled, trebled, and so on, till at last we have a pint or a quart of glue water. The jelly will thus become thinner and thinner, and the amount of constraining force which it can bear without being dislocated will become less and less. At last it will become so far fluid as to mend itself again as soon as it is dislocated. Yet there seems hardly sufficient reason for supposing that at a certain stage of the dilution the tangential force whereby it resists constraint ceases all of a sudden. In order that the medium should not be dislocated, and therefore should have to be treated as an elastic solid, it is only necessary that the amount of constraint should be very small. The medium would however be what we should call a fluid, as regards the motion of solid bodies through it. The velocity of propagation of normal vibrations in our medium would be nearly the same as that of sound in water; the velocity of propagation of transversal vibrations, depending as it does on the tangential elasticity, would become very small. Conceive now a medium having similar properties, but incomparably rarer than air, and we have a medium such as we may conceive the ether to be, a fluid as regards the motion of the earth and planets through it, an elastic solid as regards the small vibrations which constitute light. Perhaps we should get nearer to the true nature of the ether by conceiving a medium bearing the same relation to air that thin jelly or glue water bears to pure water. The sluggish transversal vibrations of our thin jelly are, in the case of the ether, replaced by vibrations propagated with a velocity of nearly 200,000 miles in a second: we should expect, *à priori*, the velocity of propagation of normal vibrations to be incomparably greater. This is just the conclusion to which we are led quite independently, from dynamical principles of the greatest generality, combined with the observed phenomena of optics*.

* See the introduction to an admirable memoir by Green, "On the laws of the Reflexion and Refraction of Light at the common surface of two non-crystallized media." *Cambridge Philosophical Transactions*, Vol. VII. p. 1.