II. *On the Constitution of the Luminiferous Æther, viewed with reference to the phænomenon of the Aberration of Light. By* G. G. Stokes, *M.A., Fellow of Pembroke College, Cambridge*.*

IN a former communication to this Magazine (July 1845), I showed that the phænomenon of aberration might be explained on the undulatory theory of light, without making the startling supposition that the earth in its motion round the sun offers no resistance to the æther. It appeared that the phænomenon was fully accounted for, provided we supposed the motion of the æther such as to make

$$u\, dx + v\, dy + w\, dz \quad \cdots \quad \cdots \quad (a.)$$

an exact differential, where u, v, w are the resolved parts, along three rectangular axes, of the velocity of the particle of æther whose co-ordinates are x, y, z. It appeared moreover that it was necessary to make this supposition in order to account in this way for the phænomenon of aberration. I did not in that paper enter into any speculations as to the physical causes in consequence of which $(a.)$ might be an exact differential. The object of the present communication is to consider this question.

The inquiry naturally divides itself into two parts:—*First,* In what manner does one portion of æther act on another beyond the limits of the earth's atmosphere? *Secondly,* What takes place in consequence of the mutual action of the air and the æther?

In order to separate these two questions, let us first conceive the earth to be destitute of an atmosphere. Before considering the motion of the earth and the æther, let us take the case of a solid moving in an ordinary incompressible fluid, which may be supposed to be infinitely extended in all directions about the solid. If we suppose the solid and fluid to be at first at rest, and the solid to be then moved in any manner, it follows from the three first integrals of the ordinary equations of fluid motion, obtained by M. Cauchy, that the motion of the fluid at any time will be such that $(a.)$ is an exact differential. From this it may be easily proved, that if at any instant the solid be reduced to rest, the whole of the fluid will be reduced to rest likewise; and that the motion of the fluid is the same as it would have been if the solid had received by direct impact the motion which it has at that instant. Practically however the motion of the fluid after some time would differ widely from what would be thus obtained, at least if the

motion of the solid be progressive and not oscillatory. This appears to be due to two causes; first, the motion considered would probably be unstable in the part of the fluid behind the solid; and secondly, a tangential force is called into play by the sliding of one portion of fluid along another; and this force is altogether neglected in the common equations of hydrodynamics, from which equations the motion considered is deduced. If, instead of supposing the solid to move continuously, we supposed it first to be in motion for a very small interval of time, then to be at rest for another equal interval, then to be in motion for a third interval equal to the former, and so on alternately, theoretically the fluid ought to be at rest at the expiration of the first, third, &c. intervals, but practically a very slight motion would remain at the end of the first interval, would last through the second and third, and would be combined with a slight motion of the same kind, which would have been left at the end of the third interval, even if the fluid immediately before the commencement of it had been at rest; and the accumulation of these small motions would soon become sensible.

Let us now return to the æther. We know that the transversal vibrations constituting light are propagated with a velocity about 10,000 times as great as the velocity of the earth; and Mr. Green has shown that the velocity of propagation of normal vibrations is in all probability incomparably greater than that of transversal vibrations (Cambridge Philosophical Transactions, vol. vii. p. 2). Consequently, in considering the motion of the æther due to the motion of the earth, we may regard the æther as perfectly incompressible. To explain dynamically the phænomena of light, it seems necessary to suppose the motion of the æther subject to the same laws as the motion of an elastic solid. If the views which I have explained at the end of a paper On the Friction of Fluids, &c. (Cambridge Philosophical Transactions, vol. viii. part 3) be correct, it is only for extremely small vibratory motions that this is the case, while if the motion be progressive, or not very small, the æther will behave like an ordinary fluid. According to these views, therefore, the earth will set the æther in motion in the same way as a solid would set an ordinary incompressible fluid in motion.

Instead of supposing the earth to move continuously, let us first suppose it to move discontinuously, in the same manner as the solid considered above, the æther being at rest just before the commencement of the first small interval of time. By what precedes, the æther will move during the first interval in the same, or nearly the same, manner as an incompres-

sible fluid would; and when, at the end of this interval, the earth is reduced to rest, the whole of the æther will be reduced to rest, except as regards an extremely small motion, of the same nature as that already considered in the case of an ordinary fluid. But in the present case this small motion will be propagated into space with the velocity of light; so that just before the commencement of the third interval the æther may be considered as at rest, and everything will be the same as before. Supposing now the number of intervals of time to be indefinitely increased, and their magnitude indefinitely diminished, we pass to the case in which the earth is supposed to move continuously.

It appears then, from these views of the constitution of the æther, that (*a.*) must be an exact differential, if it be not prevented from being so by the action of the air on the æther. We know too little about the mutual action of the æther and material particles to enable us to draw any very probable conclusion respecting this matter; I would merely hazard the following conjecture. Conceive a portion of the æther to be filled with a great number of solid bodies, placed at intervals, and suppose these bodies to move with a velocity which is very small compared with the velocity of light, then the motion of the æther between the bodies will still be such that (*a.*) is an exact differential. But if these bodies are sufficiently close and numerous, they must impress either the whole, or a considerable portion of their own velocity on the æther between them. Now the molecules of air may act the part of these solid bodies. It may thus come to pass that (*a.*) is an exact differential, and yet the æther close to the surface of the earth is at rest relatively to the earth. The latter of these conditions is however not necessary for the explanation of aberration.

There is one curious consequence of the theory contained in my paper of last July, which I did not at the time observe. On referring to this paper, it will be seen that if the motion of the æther is such that (*a.*) is an exact differential, the change in the direction of the normal to a wave of light, as the wave passes from a part of space where the disturbance of the æther due to the motion of the earth is insensible to another part where the disturbance is sensible, is given by the equation

$$\alpha_2 - \alpha_1 = \frac{u_2}{V},$$

which is what (6.) becomes when u_1 and v_1 are each put equal to zero; and the plane passing through the direction of the

light and the direction of the motion of the æther at the point considered is taken for the plane $x\,z$. Now, in consequence of the motion of the æther, the direction of the light in space will deviate from the normal to the wave through the angle $\frac{u_2}{V}$ in the contrary direction, as may be very easily shown (see Phil. Mag. for February 1846, p. 78). Hence the direction of the light coming from a star is the same as that of a right line drawn from the star, not merely at such a distance from the earth that the motion of the æther is there insensible, and again close to the surface of the earth, where the æther may be supposed to move with the earth, but *throughout the whole course* of the light; so that a ray of light will proceed in a straight line even when the æther is in motion, provided the motion be such as to render (*a.*) an exact differential. The orthogonal trajectory represented in fig. 2 of my paper of July, must not be confounded with the path of a ray of light. In that paper I supposed that the æther close to the surface of the earth was at rest relatively to the earth; in fact, the very object of the paper was to get rid of the apparent necessity of supposing the æther to pass through the whole atmosphere and through the earth itself. It should be observed, however, that the phænomenon of aberration allows us to suppose that the æther passes through the atmosphere and through the earth with any velocity, either constant, or varying from point to point, provided only (*a.*) be an exact differential.

P.S. I take this opportunity of adding a few words on the subject of Prof. Challis's last communication. There is nothing so far as I can make out in which we differ, except the sense in which we use the expression *explaining* a phænomenon from certain causes. According to my use of the term, a person would be said to explain a phænomenon when he has shown that certain causes being assumed, the phænomenon would necessarily follow. In this sense we explain the formation of images in common optics, assuming the properties of rays. We are able to show what must be the form, &c. of the image. In this sense Prof. Challis has not explained aberration by assuming *merely* the motion of the earth and the velocity of light, since, for aught that appears from his reasoning, a star might be displaced through double the angle through which it is observed to be displaced. It was for this reason, that in order to allow that Prof. Challis had explained aberration, I attached, in a former communication, a peculiar meaning to the word *aberration.*

We may divide the causes which we might conceive concerned in the production of aberration into three:—(1), the motion of the earth; (2), the velocity of light; (3), the change in the direction of the light coming to the earth. Professor Challis has shown that a certain apparent displacement of a star would result from the first two causes; and *as this happens* to be the whole displacement observed (neglecting a quantity which may be considered insensible), so that there is none left to be attributed to the third cause, he says that he has explained aberration, assuming merely the first two causes. It is evident that the two senses attached to the words, *to explain a phænomenon*, are quite different. According to the sense in which I used the words, the explanation of the absence of any change in the final direction of the light would have to be included in any theory which professed to explain aberration by means of the first two causes *only*. In the present communication I have used the words in my own sense, for I believe that there is no impropriety in it; but Prof. Challis may, if he pleases, consider the object of my July paper to have been the explanation, not of aberration, but of the absence of any change in the final direction of the light. Whichever of these results be arrived at, the other readily follows.

III. *On Electrical Endosmose.*   By Mr. James Napier[*].

THAT two dissimilar solutions, separated by a porous partition, will pass the one into the other, is a phænomenon long observed, the only necessary condition being that the liquids have a strong tendency to combine, and that the one is more capable of entering into or wetting the porous partition than the other. The liquids eminently fitted to effect this are alcohol and water, and saturated solutions of some salts and pure water. But the phænomenon of endosmose takes place also when an electric current passes through liquids separated by a porous partition. When all the above conditions are absent, and even when these conditions are present, the endosmotic current will follow the electric, although in a contrary direction to that which would take place were there no electric current passing, showing that, under these circumstances, it has its origin in the passage of the electric force. This fact was first made known by Mr. Porrett in the Annals of Philosophy for 1816.

The object of this paper is not to define the cause, but to point out the different conditions of electrical endosmose, and the important part it plays in electro-chemical investigation.

The conditions under which electrical endosmose are observed, are, that the two metals constituting a battery, or the two electrodes of a battery, be placed in separate vessels or divisions of the same vessel; one of the vessels, or partition, being composed of a material sufficiently close in texture to prevent the mixture of the two liquids, and porous enough to allow the electricity to permeate through it. The substances generally used are bladder, parchment, unglazed porcelain, &c. The last is what I have generally used in the experiments to be detailed.

The general effects of electrical endosmose are, a portion of the positive solution passes along with the electric current into the negative solution, not by electrolytic action, as has been generally supposed, but by endosmotic action; and this endosmotic current is confined to the direct influence of the electric current, or facing the metals composing the electrodes or battery. There are some circumstances in which the positive solution gains in quantity, making an apparent current contrary to the electrical; these will be referred to as we proceed.

Electrical endosmose manifests itself in two ways, or rather is of two kinds, which may be distinguished as the *measurable* and the *unmeasurable*, the former being the result of the transfer of water from one cell to another, the latter of a salt or acid held in solution, and which is being decomposed; this may take place to an extent equal to the whole salt held in solution in the positive cell without the quantity of the two solutions being materially altered; and that this transfer is from endosmose will be best illustrated by detailing a few experiments, stating however that the investigation necessarily involves a great number of experiments, the whole of which I cannot detail, and the conclusions come to have been the result of these. It may be stated here that the vessel or division in which the positive electrode or metal is placed is termed the positive solution, and the negative division the negative solution.

I. 20 ounces of water, in which were dissolved 500 grains of sulphate of copper, were made the positive solution, and other 20 ounces of water, with 500 grains of sulphate of copper, were made the negative solution. A copper electrode, previously weighed, was put into each of these solutions and connected with a Wollaston's battery of nine pairs, the current