Translation:The Relative Motion of the Earth and the Aether

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H. A. LORENTZ

To explain the aberration of light it was assumed by FRESNEL, that the aether does not share the annual motion of earth, which of course requires that our planet is completely permeable for that medium. Later, STOKES sought an explanation on the assumption that the aether is dragged by the earth and thus to each point at the earth's surface the speed of the aether is the same as that of the earth.

On these theories, I have extensively worked some years ago[1]. It appeared to me that other modes of explanation may more or less lie in the middle between those mentioned above, and therefore, as they are not so simple, deserve less attention. Of the two extreme views I thought it was necessary to reject that of STOKES, because the motion of the aether requires the existence of a velocity potential, which is incompatible with the equality between the velocities of the earth and the adjacent aether

On the other side, it was possible to explain nearly all considered phenomena by FRESNEL's theory, if we assume the "dragging coefficient" for transparent ponderable substances given by FRESNEL, and whose value was recently derived by me from the electromagnetic theory of light.[2]

A great difficulty was posed by an interference experiment, executed by MICHELSON[3] in order to decide between the two theories.

It was noted by MAXWELL, that if the aether remains at rest, then the motion of earth must have an influence on the time required by light to travel forth and back between two points regarded as fixed to earth. If l is the distance of the points, V the velocity of light, and p that of earth, then the relevant time is given by (if the line of points is parallel to the direction of motion):

$$2\frac{l}{V}\left(1+\frac{p^2}{V^2}\right) \tag{1}$$

and if it is perpendicular to it

$$2\frac{l}{V}\left(1+\frac{p^2}{2V^2}\right) \tag{2}$$

making a difference of

$$\frac{lp^2}{V^3} \tag{3}$$

Michelson used a device with two equally long-standing horizontal arms perpendicular to each other, with mirrors at the ends and perpendicular to their direction. An interference phenomenon occurred, when (from the radius of the intersection) a ray traveled forth and back along one arm, and another along the other arm. The entire device - including the light source and the observation telescope - could be rotated around a vertical axis, and the observation time was chosen, so that one can bring, as good as possible, one arm or the other arm into the direction of motion of earth. Let us assume for convenience that this is really the case, then - if FRESNEL's theory is correct - due to the earth's motion the rays that travel forth and back into the earth's direction, must suffer a certain delay determined by (3) in respect to the other ray. When rotated by 90°, all phase shifts must be altered by an amount, which, expressed in unit time, can be given by the double of magnitude (3). But a displacement of the interference fringes could not be observed.

Against this experiment one can argue, that the length of the arms are just too small to obtain any observable displacement of the fringes. But MICHELSON together with MORLEY repeated the experiment on a larger scale.[4] The light rays were traveling forth and back in mutually normal directions several times, because they were reflected every time by mirrors; the latter as well as all other parts of the apparatus stood on a stone plate, that swam on mercury and which could be rotated in horizontal direction. However, the shift as required by FRESNEL's theory could not be observed again.

I have sought a long time to explain this experiment without success, and eventually I found only one way to reconcile the result with FRESNEL's theory. It consists of the assumption, that the line joining two points of a solid body doesn't conserve its length, when it is once in motion parallel to the direction of motion of Earth, and afterwards it is brought normal to it. If for example the distance in the latter case is l and in the first case $l(1-\alpha)$, then the first expressions (1) and (2) have to be multiplied by $1-\alpha$. Neglecting $\frac{\alpha p^2}{V^2}$, one obtains

$$2\frac{l}{V}\left(1+\frac{p^2}{V^2}-\alpha\right)$$

The difference to (2) - and thus the whole objection - would be removed when

$$\alpha=\frac{p^2}{2V^2}$$

Such a change in length of the arms in MICHELSON's first experiment, and in the size of the stone plate in the second, is really not inconceivable as it seems to me.

Indeed, what determines the size and shape of a solid body? Apparently the intensity of molecular forces; any cause that could modify it, could modify the shape and size as well. Now we can assume at present, that electric and magnetic forces act by intervention of the aether. It is not unnatural to assume the same for molecular forces, but then it can make make a difference, whether the connecting line of two particles, which move together through the ether, is moving parallel to the direction of motion or perpendicular to it. One can easily see, that an effect of order $\frac{p}{v}$ is not expected, but an effect of order $\frac{p^2}{V^2}$ is not excluded and that is exactly what we need.

Since we know nothing about the nature of molecular forces, it is impossible to verify the hypothesis. We only can - of course by introducing more or less plausible assumptions - calculate the influence of the motion of ponderable matter on electric and magnetic forces. Perhaps it is worth mentioning, that when the result obtained for the electric forces is transferred to molecular forces, it exactly gives the value of α given above.

Let A be a system of material points, which bear certain electrical charges and which are at rest relative to the aether, and B is the system of the same points, when they are moving in the direction of the x-axis by the collective velocity p through the aether. From the equations developed by me[5] one can deduce, by which forces the particles in the system act on each other. The result can be expressed in the most simple way, if one introduces a third system C that is at rest like A, but differs from the latter system by the mutual position of the points. System C can be obtained from A by a mutual expansion, by which all dimensions in the direction of the x-axis are $1+\frac{p^2}{2V^2}$ times larger, while the perpendicular dimensions remain unchanged.

Concerning the relation between the forces in B and C it follows, that the components in the direction of the x-axis are the same as in C, while the components perpendicular to the x-axis are $1-\frac{p^2}{2V^2}$ times larger as in C.

We want to transfer this to the molecular forces, and imagine a solid body as a system of material points, in equilibrium by the influence of their mutual attractions and repulsions. The system B shall be a body moving through the aether. The forces acting on its material points eliminate each other. It follows, that this cannot be the case in A, however, in system C all force-components perpendicular to the x-axis are changed if one goes over from B to C, but the equilibrium will not be disturbed as they are changed in the same ratio. In this way it can be seen, that when B is the state of equilibrium of the body during the displacement in the aether, C is the state of equilibrium when the displacement doesn't exist. One therefore comes exactly to the influence of motion on the dimensions, which was shown before to be necessary to explain MICHELSON's experiment.

Of course we cannot ascribe great importance to this result; the transfer to molecular forces of what we have found for electrical forces, may be too risky for some. Moreover, if we want to do this, it remains undecided whether earth's motion shortens the dimensions in one direction - as it was supposed before - or elongates the length perpendicular to it, by which assumption we could reach the same result.

Anyway, it seems undeniable that changes of the molecular forces and consequently of the body's size of order $1-\frac{p^2}{2V^2}$ are possible. MICHELSON's experiment thus loses its verification power for the question at which it was aimed. If one assumes the theory of FRESNEL, then its meaning rather lies in the fact, that we can learn something about the change of dimensions.

As $\frac{p}{V}=\frac{1}{10000}$, then $\frac{p^2}{2V^2}$ is the two hundred millionth. A contraction of the diameter of the Earth by this ratio would amount 6 cm. We cannot speak about the observation of a change in length of two hundred millionth when comparing meter sticks, and even if an observation method would allow this, then this method would be the juxtaposition of two sticks, but we would never detect the discussed changes, when they occur in the same way for both of them. The only remedy is to compare the length of two sticks perpendicular to each other, and if we want to do this by the observation of an interference phenomenon (with a light ray that travels back and forth along the first and the other ray along the second arm), then we would come back to MICHELSON's experiment. The influence of the change in length, however, would be compensated by the change of phase shift which is determined by expression (3).

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1. *Verslagen en Mededeelingen* 3de Reeks, Deel II, p. 297, 1886. *Archives néerlandaises*, T. XXI, p. 103. 1887.
2. *Archives néerlandaises*, T. XXV, p. 363. 1892.
3. *American Journal of Science*, 3d Ser. Vol. XXII, p. 120.
4. *American Journal of Science*, 3d Ser. Vol. XXXIV, p. 383. 1887.
5. *Archive néerlandaises*, T. XXV. p. 498.