the general science journal

LETTER FROM AUGUSTIN FRESNEL TO FRANÇOIS ARAGO CONCERNING THE INFLUENCE OF TERRESTRIAL MOVEMENT ON SEVERAL OPTICAL PHENOMENA[1]

Item XLIX in Fresnel's *Oeuvres Complètes* (1966-70).
Originally published in *Annales de chimie et de physique*, **9**, 57; (Sep 1818).

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My dear friend,

By your fine experiments on the light from stars, you have demonstrated that the movement of the terrestrial globe has no noticeable influence on the refraction of rays emanating from these stars. As you pointed out, one can only explain this remarkable result, within the theory of emission[2], by supposing that the light sources impart to the particles of light an infinite variety of different speeds, and that these particles will affect the organ of sight with only one of these speeds, or at least between very narrow limits such that about one ten-thousandth is more than enough to prevent the sensation. The necessity for this hypothesis is not amongst the most trivial difficulties for the theory of emission; for what does vision depend on? — On the impact of luminous particles against the optic nerve? But this impact will not become unnoticeable by an increase in speed. — On the manner in which it is refracted in the pupil? But the red particle, for example, for which the speed will be diminished by some 2%, would be refracted still less than the violet rays, and would not run outside the bounds of the spectrum, which constitutes the limits of vision.[3]

You have inspired me to investigate whether the result of these observations could be more easily reconciled with the system which takes light as consisting of vibrations in a universal fluid. It is all the more necessary to explain these results using this theory,

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[1] Extract from the letter to Léonor Fresnel, 5 September 1818 (LIX):
" … I have lately done a little project to which I attach some importance. I have proved that, supposing the earth is porous enough for it to impose on the ether which penetrates and surrounds it only a very small part of its speed, which would not exceed 1% for example, then one could adequately explain, not only the aberration of the stars, but also the other complicated optical phenomena of terrestrial movement, etc."
[*1866 editor*]

[2] Emission theory (or corpuscular theory, as favoured by Newton) — postulating that light consists of emitted particles. If true, this would strongly suggest that these particles would have their speed anchored to that of the emitting body; i.e. that their velocity would be "source-controlled". [RRT, 2002]

[3] Modern readers might well find fault with these objections, but they will be able to offer new objections such as energy-conservation considerations. [RRT]

since it must apply equally to terrestrial objects; for the speed with which the waves are propagated is independent of the movement of the bodies from which they emanate.

If one supposed that our globe impresses its motion on the ether in which it is enveloped, one would easily conceive why the same prism always refracts light in the same manner, whatever the side from which the light may arrive. But it seems impossible to explain the aberration of stars by this hypothesis: I have not been able, so far at least, to account for this phenomenon clearly except by supposing that the ether passes freely through the globe, and that the speed communicated to this subtle fluid is only a small fraction of that of the earth, not exceeding one hundredth of it, for example.

However extraordinary this hypothesis might seem to be at first, it is not in contradiction, it seems to me, with the idea that has been put forward by the greatest physicists concerning the extreme porosity of bodies. One may ask, as a matter of fact, how a very thin opaque layer of matter, shutting off the light, happens to set up an ether current through our globe. Without claiming to answer this objection completely, I will remark meanwhile that these two sorts of movement are of a nature too different for us to be able to use our observations of the one as being applicable to the other. The luminous movement is by no means a current, but rather a vibration of the ether. One conceives that the small elementary waves in which the light divides itself while passing through the body are able, in certain cases, to find themselves out of phase at the moment when they re-unite, due to the difference of path travelled, or to the unequal retardations which they have experienced in their progress; — the very phase disruption which prevents the propagation of vibrations, or distorts them so as to remove their property of illumination, just like what takes place in a very striking manner in black bodies; whereas the same circumstances would not impede the establishment of an ether current. One increases the transparency of 'hydrophane'[4] by wetting it, and it is clear that the interposition of water between the particles, which favours the propagation of the luminous vibrations, must on the other hand be a slight additional obstacle to the establishment of an ether current; a consideration which well demonstrates the great difference which exists between the two types of movement.

The opacity of the Earth is thus no sufficient reason for denying the existence of an ether current between its molecules, and one might suppose it porous enough for it to communicate only a very small part of its movement to this fluid.

With the help of this hypothesis, the phenomenon of aberration[5] is as easy to conceive in the wave theory as in the emission theory; for it results from the displacement of the telescope while the light travels through it: now, according to this hypothesis, the luminous waves do not perceptibly participate in the movement of the telescope, which I assume to be directed toward the true position of the star, the image of this star finds

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[4] or paper — using water *or* oil, etc. [RRT, 2002]

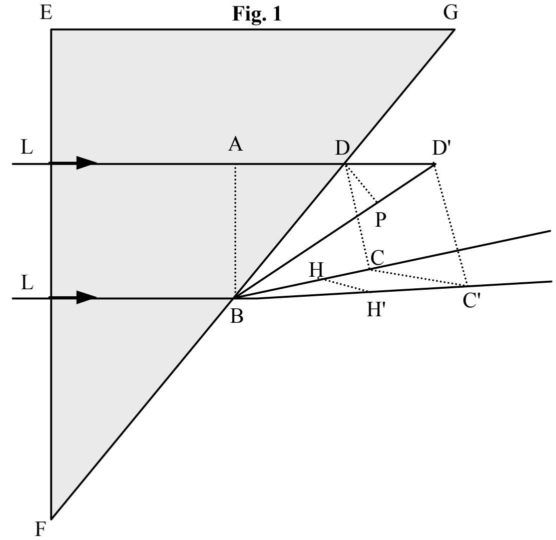
[5] When the Earth is moving perpendicular to the direction of a star, the light from that star appears to be coming from a direction slightly ahead (with respect to the Earth's motion). This phenomenon is called *aberration*. See Jenkins and White (1950) page 379. [RRT].

itself left behind the thread placed at the focus of the eyepiece, by a distance equal to that which the Earth has traversed whilst the light passes through the telescope.

It is now a question of explaining, by the same hypothesis, how it is that apparent refraction does not vary with the direction of the luminous rays relative to terrestrial movement.

Let EFG (fig. 1) be a prism of which the face EF is taken to be perpendicular to both the ecliptic[6] and to the incident rays, which thus turn out to be in the direction of the Earth's movement: giving the case where the terrestrial motion must be most perceptible — if it is able to influence the refraction of rays at all. I assume that the rays are travelling in the same direction as the prism [*i.e. left to right; RRT*].

Fig. 1



The rays, being perpendicular to the surface of entry, do not experience any refraction at this side of the prism, and one has to consider only the effect produced by the second surface. Let LD and LB be two of these rays which reach the surface of exit at the points D and B. Let BC be the direction which the ray LB takes on leaving the prism, in the case in which that prism is stationary. If one drops a perpendicular from point D to the emerging ray, and draws BA perpendicularly from the point B into the incident rays; then the light must traverse AD in the same time-interval as BC: such is the law which determines the direction of the refracted wave-interval DC. [Huygen's Principle; RRT]. But whenever the prism is being carried along by the Earth's movement whilst the light traverses the interval AD, then the point D will be displaced. This change, augmenting the difference of traversed path in the glass by the two rays LD and LB, must change the angle of refraction. FG representing the position of the surface-of-emergence at the moment when the incident wave has arrived at AB, let D' be the point where the ray AD reaches that surface and leaves the prism. Let BC' be the new direction of the refracted rays. The perpendicular[7] D'C' will be that of the emerging wave-front, which will have to satisfy the general condition that AD' should be traversed by the light in the same time as BC'. But to determine the relationship of length between the two intervals, it remains to calculate the variation which the movement of the prism brings to the speed of the luminous waves which traverse it.

If the prism carries along with it all the ether which it contains, (the whole of the medium which serves as a vehicle for the waves would thus be sharing in the Earth's movement), then the speed of the luminous waves will be that which they must have in the medium taken to be stationary, augmented by the speed of the Earth. But the case in

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[6] The *ecliptic* is the plane of the Earth's motion around the Sun. [RRT]

[7] The (assumed) frame of reference is presumably that of the ether in that local vicinity — which is not necessarily the same as that of the "stationary" observer; hence the distorted "right-angle". [RRT]

question is more complicated; it is only part of the ether medium which is carried along by our globe, that part which makes up the excess of its 'density'[8] over that of the surrounding ether. The analogy indicates that, when only a part of the ether medium is displaced, the propagation speed of the waves would only have to be augmented by the speed of the centre of gravity of the ether system.

This principle is evident for the case where the part in motion is half of the medium; for, in relating the system's movement to its optical 'centre of gravity', considered as fixed for an instant, its two halves will separate away from each other with equal and opposite velocities; it follows from this that the waves must be just as much retarded in one direction as they are accelerated in the other, and that they have only the ordinary speed of propagation in relation to the 'centre of gravity', or, what comes to the same thing, that they participate in its motion. If the mobile part were a quarter, an eighth, a sixteenth, etc. of the medium, one would show just as easily that the speed additional to that of the propagation of the waves is a quarter, an eighth, a sixteenth, etc. of that moving part, or the same speed as the 'centre of gravity', and it is clear that the theorem, being independent of all these particular cases, must be true in general.

Granting this, the prismatic medium being in equilibrium with the surrounding ether (I will suppose, for greater simplicity, that the experiment is performed in vacuo), one may consider the retardation of light in the prism when it is at rest, as resulting uniquely from its greater 'density'[9]; and this assumption gives the means for determining the relationship between the 'densities' of the two media; for one knows that it must be inverse to the squares of the wave propagation velocities. Let d and d' be the wavelengths of the light in the surrounding ether and in the prism, respectively; Δ and Δ' the 'densities' of these two media; one then has the proportion:

$$d^2 : d'^2 :: \Delta' : \Delta \;;$$

so that

$$\Delta' = \Delta \; (d^2/d'^2) \;,$$

and consequently

$$\Delta' - \Delta = \Delta \left(\frac{d^2 - d'^2}{d^2}\right)$$

Such is the 'density' of the moving part of the prismatic medium. If one represents by t the distance which the Earth traverses during one light oscillation, then the

[8] "Densité" is used in an optical sense rather than a mass-related sense; see footnote on page .... However such a usage would appear to be obvious when applied to an *ether* which is presumably massless. [RRT]

[9] The modern reader should presumably interpret this 'density' as meaning "dielectric constant (for that frequency", (cf. Jenkins and White, 1950, §23.8). It is scarcely likely that Fresnel would have seen any such implied connection with electrical theory, but he does acknowledge in the PS of November 1818 (see below) that there is probably an *'elasticity'* component within this 'density' — and possibly an isotropic elasticity at that. [RRT]

displacement of the ‘centre of gravity’ of the medium during the same interval of time (which I take as unity) — i.e. the speed of the ‘centre of gravity’ — will be:

$$t\left(\frac{d^2-d'^2}{d^2}\right)$$

Consequently the wavelength d'' within the prism carried along by the Earth will be equal to

$$d' + t\left(\frac{d^2-d'^2}{d^2}\right)$$

In calculating, with the aid of this expression, the distance AD' (fig. 1) travelled by the ray AD before its exit from the prism, one may easily determine the direction of the refracted ray BC'. If one compares this direction with that of the same ray BC', in the case where the prism is stationary, one discovers for the sine of the angle CBC', the expression:

$$(t/d')\sin i\cos i \;-\; (t/dd')\sin i\;\sqrt{d'^2 - d^2\sin^2 i}$$

— (neglecting all the terms multiplied by squares and higher powers of *t*, because of the smallness of *t*)

where i represents the angle of incidence ABD.

I shall suppose that, from any point H on the ray BC, one draws a line HH' parallel to the ecliptic and equal to the distance travelled by the Earth during the time taken by the light to go from B to H'; the optic axis of the telescope (with which one observes the target-object) being pointed in the direction of BH, the light must follow the direction BH' to arrive at H' in the same time that the thread-line of the telescope moves along with the Earth's motion: now the line BH' coincides precisely with the direction BC' of the ray refracted by the prism carried along in the same motion; for one finds also, for the value of sin HBH', the expression

$$(t/d')\sin i\cos i \;-\; (t/dd')\sin i\;\sqrt{d'^2 - d^2\sin^2 i}$$

Thus one must place the telescope in the same direction as if the prism were stationary; from which it follows that the motion of our globe must not have any noticeable influence on the apparent reflection, even when one assumes that it communicates only a very small part of its velocity to the ether. One may assure oneself, by a very simple calculation, that it must be the same with reflection. So this hypothesis, which gives an adequate explanation for aberration, does not lead to any inference contrary to the observed facts.

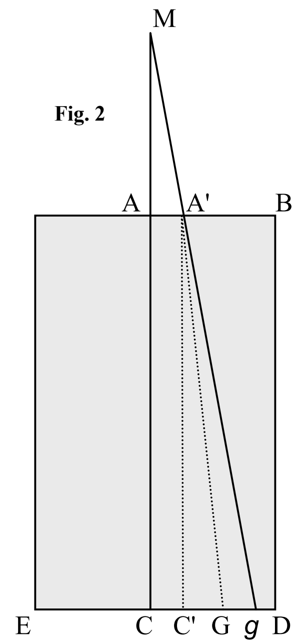
I shall finish this letter with an application of the same theory to an experiment proposed by Boscovich[10], consisting of observing the phenomenon of aberration with a telescope filled with water, or another fluid much more refringent than air, to make it

[10] This experiment was later performed by Airy in 1872 (Jenkins and White, 1950, page393). [RRT].

clear whether the direction in which one perceives a star must vary due to the change which the liquid brings to the progress of the light. I would remark first that there is no need to complicate the effect one is seeking by introducing aberration, and that one might just as well determine the effect by aiming at a terrestrial object as by aiming at a star. This then, it seems to me, is the simplest and most convenient way of doing the experiment.

One could attach the target object M to the structure of the telescope itself — or rather to the *micro*scope, FRDE (fig. 2). With this target object fixed on the extension of an optic axis CA, one would point this system perpendicularly to the ecliptic, and, after having made the observation in one direction, one would turn it round end-for-end, and one would make the observation in the opposite direction. If the Earth's motion displaced the image of point M, in relation to the thread-line of the eyepiece, one would see it just as much to the right of the thread as to the left, in this example.

Fig. 2



According to the emission theory, it is clear, as Wilson has already remarked, that the terrestrial movement is destined to make no change to the appearances of the phenomena. Indeed, it follows from this movement that the ray leaving M must take (in order to go through the centre of this objective) a direction MA' such that the distance AA' would be traversed by the globe in the same interval of time that the light takes to traverse MA', or MA (on account of the smallness of the speed of the Earth relative to that of light). Representing by v the speed of light in the air, and by t that of the Earth, one then has:

$$\text{MA} : \text{AA}'' \ :: \ v : t, \qquad \text{or} \qquad \frac{\text{AA}'}{\text{MA}} = \frac{t}{v} \quad ;$$

the sine of the angle of incidence. If v' is the speed of light in the denser medium which is contained in the telescope, then the angle of refraction C'A'G will be equal to (t/v'). One will have then $\text{C'G} = \text{A'C'}(t/v')$; from which one derives the proportion

$$\text{C'G} : \text{A'C'} \ :: \ t : v' \ .$$

Consequently the thread-line C' of the eyepiece placed in the optic axis of the telescope will reach G at the same time as the luminous ray which has gone through the centre of the objective.

The wave theory leads to the same result. I assume, for greater simplicity, that the microscope is in vacuo. If d and d' are, respectively, the speeds of light in vacuo and in the medium which is contained in the telescope, then for rhe sine of the angle of incidence AMA', one finds (t/d), and for the sine of the angle of refraction C'A'G, one finds (td'/d^2). Thus, independently of the displacement of the waves in the direction of the Earth's movement, C'G = A'C' (td'/d^2). But the speed with which these these waves are carried along by the mobile part of the medium in which they propagate is equal to

$$t\left(\frac{d^2 - d'^2}{d^2}\right) \;;$$

then their total displacement G*g*, during the time that they take to traverse the telescope, is equal to

$$\frac{\mathrm{A'C'}}{d'}\, t\left(\frac{d^2 - d'^2}{d^2}\right) \;;$$

thus

$$\mathrm{C'}g = \mathrm{A'C'}.t\left(\frac{d'}{d^2} + \frac{d^2 - d'^2}{d'd^2}\right) = \mathrm{A'C'}.t\left(\frac{d^2}{d'd^2}\right) = \mathrm{A'C'}.\frac{t}{d'},$$

One then has the proportion C'*g* : A'C' :: t : d' ; consequently the image of the point M will reach *g* at the same time as the thread-line of the micrometer. Thus the appearances of the phenomena must always remain the same whatever the direction in which one turns this instrument. Although this experiment may not yet have been performed, I do not doubt but that it would confirm this consequence, that one deduces equally from the emission theory and from the wave theory.

ADDITIONAL NOTE TO THIS LETTER

(from *Annales de chimie et de physique*, **9**, 286. — Issue for November 1818) [1866 editor]

In calculating the refraction of light in a prism carried along by the Earth's movement, I assumed, to simplify the reasoning, that the difference between the speeds of light in the prism and in the surrounding ether arose uniquely from a difference of density, the elasticity being the same in both parts; but it is very likely that the two media do differ in elasticity as in density. One even conceives that the elasticity of a solid body is able to vary with the direction along which one considers it; and it is very probably this which gives rise to double refraction, as Dr Young has observed. But whatever the hypothesis which one might make on the causes of the slowing down of the progress of light in transparent bodies, one can always, (to resolve the problem which I have proposed), mentally replace the real medium of the prism by an elastic fluid in equilibrium with the ether environment, and of a density such that the speed of light would be precisely the same in this fluid and in the prism — both taken to be at rest; this equality will have to continue in existence within the two media carried along by the Earth's movement: — at least such are the bases on which my calculation rests.

Translator's note:- In this text, "speed" and "velocity" are both used as equivalents for Fresnel's word "vitesse". [RRT]