tion, which confers great credit on Mr. Stevenson, to whom we are much indebted for it; and he will observe that I expressly described it to the meeting of the Franklin Institute, Sept. 19, 1850, (see vol. xx, 3d series of this Journal, page 236,) as his; and he, I am happy to be informed, has additional merit in carrying it into actual practice. G. W. SMITH.

Translated for the Journal of the Franklin Institute.

Physics.—Upon the hypotheses relative to Luminous Ether, and upon an experiment which seems to demonstrate that the motion of Bodies changes the velocity with which light is propagated within them. By M. H. FIZEAU. (Extract by the Author.)

Numerous theories have been proposed to account for the phenomenon of aberration on the system of undulations. Fresnel, in the first place, and more recently Messrs. Doppler, Stokes, Challis, and several others, have published important articles on this subject; but it appears that none of these theories have received the entire assent of natural philosophers. Indeed, in the absence of certain knowledge of the properties of luminous ether, and of its relations to ponderable matter, it has been found necessary to make hypotheses, and amongst those which have been proposed, there are several more or less probable, but none which may be considered as proved.

These hypotheses may be reduced to three principal ones. They have reference to the condition in which the ether existing in the interior of a transparent body is to be conceived.

Either the ether is adherent, and as it were, attached to the molecules of a body and consequently partakes of the motion which may be given to that body:

Or, the ether is free, independent, and is not carried along by the body in its movements:

Or, finally, by a third hypothesis, which partakes of the other two, a portion only of the ether is free, the other portion is fixed to the molecules of the body, and that alone moves within it.

This last hypothesis, which we owe to Fresnel, was started with the view of accounting at the same time for the phenomenon of aberrations, and a celebrated experiment of Mr. Arago, by which it is shown, that the motion of the earth is without influence upon the refraction which the light of the stars undergoes in a prism.

We can examine the value, which, for each of these hypotheses, is to be given to the velocity of light in bodies, when we suppose those bodies in motion. The value of these velocities may be changed by the fact of the motion.

If we suppose that all the ether is carried along with the body, the velocity of the light will be augmented by the entire velocity of the body, supposing the ray to be projected in the direction of the motion. If the ether is supposed to be free, the velocity of the light will not be changed.

Finally, if only a portion of the ether is carried along, the velocity of the light will be augmented, but by a fraction only of the velocity of

the body, and not by the totality, as in the first hypothesis. This consequence is not as evident as the preceding ones, but Fresnel has shown that it may be supported by very probable mechanical considerations.

Although the velocity of light is so enormous in comparison with the velocities which we are able to give to bodies, yet we possess, at the present day, means of observation so delicate, that it has been thought possible to determine by a direct experiment, what is really the influence of the motion of bodies on the velocity of light.

We owe to Mr. Arago a method founded on the phenomenon of interferences, which is capable of indicating the smallest variation in the indices of the refraction of bodies. The observations of Messrs. Arago and Fresnel, upon the difference of refraction which exists between dry and moist air, have shown the extraordinary sensibility of this means of observation.

It is by adopting the same principle, and joining the double tube of Mr. Arago to the apparatus of two conjugate telescopes which I had employed for the determination of the absolute velocity of light, that I have been enabled to study directly in two mediums, air and water, the effects of the motion of a body on the light which traverses it.

I shall endeavor to point out, without the aid of a drawing, what was the course of the light in this experiment. From the focus of a cylindrical lens, the solar rays entered almost immediately the first telescope by a lateral opening near its focus—a transparent mirror, whose surface was at an angle of 45° to the axis of the telescope, threw them by reflection, in the direction of the object glass.

After passing out from the object glass, the rays, having become parallel to each other, arrived at a double slit, each opening of which corresponded with the entrance of one of the tubes. Thus a very narrow pencil of rays penetrated into each tube and traversed its whole length. ($1.487\text{m.} = 4\text{ft. } 10\text{in.}$)

The two pencils of light, still parallel to each other, reached the object glass of the second telescope, were refracted, and by the effect of that refraction united at its focus; there they encountered the surface of a mirror perpendicular to the axis of the telescope, and underwent a reflection, which returned them towards the object glass. But, by the effect of the reflection, the pencils had changed their route, so that that which was before to the right passed to the left after the reflection, and vice versa. After having again traversed the object glass, and thus become once more parallel to each other, they entered a second time the tubes; but as they were inverted, that which had passed through one of the tubes in going, passed through the other tube on its return.

After their second passage through the tubes, the two beams again traversed the double slit, re-entered the first telescope, and, passing through the transparent glass, interfered at its focus. There they formed, by their mutual action, fringes of interference, which were observed with an eyepiece provided with a scale of divisions at its focus.

It was necessary that the fringes should be very wide for the purpose of permitting the appreciation of small fractions of the width of a fringe. I found that this result was obtained, whilst still preserving a great intensity of light, by placing before one of the slits a thick glass, inclined in such a manner as to show the two slits by the effect of refrac-

tion, as though they were nearer to each other than they were in reality; one may thus give to the fringes variable dimensions, and choose that which is most suitable for the observations. The double passage of the light has for its object, the increase of the distance passed over within the medium in motion, and, moreover, to compensate entirely for the influence of an accidental difference of temperature, or of pressure in the two tubes, whence might result a displacement of the fringes that would be confounded with the displacement which the motion might produce, and would render the observation uncertain.

Indeed, it is very easy to see that, by this arrangement, each point, situated on the path of one of the pencils, is equally on the path of the other, so that a change in the density at any point whatever in the passage acts in the same manner on the two rays, and can not consequently have any influence upon the position of the fringes. The fact that the compensation is total, was verified by placing a thick glass before one only of the two slits, or indeed by filling with water one only of the tubes, the other being filled with air. Neither of these experiments caused the slightest change in the position of the fringes. Relative to the motion, we see, on the contrary, that the two beams are submitted to opposite influences.

If we suppose, in fact, that in the tube placed on the right the water flows towards the observer, the beam coming from the right will have passed through the tube in the direction of the motion, whereas the beam coming from the left will have passed through it in a direction contrary to the motion.

By making the water in the two tubes flow, at the same time, in directions opposed to each other, we perceive that the effects should be added. This double current being produced, we may reverse the direction, at the same time, in each tube, and the effect should again be doubled.

All these movements of the water were produced in a very simple manner, each tube being in communication by means of two branches placed near its extremities, with two glass reservoirs, on which pressure was alternately exercised by means of compressed air. Under this pressure the water passed from one reservoir to the other through the tube whose two extremities were closed by glasses. The interior diameter of the tubes was 5.3 m. (2.087 inches,) their length 1.487 m. (4 feet 10 inches;) they were of glass.

The pressure under which the flow of the water took place was perhaps more than two atmospheres. The velocity was calculated by dividing the volume of water passed over in one second by the area of the section of the tube. I should say for the purpose of anticipating an objection which might be made, that the greatest care was taken to avoid the effects of accidental movements which the pressure and shock of the water might have produced. Thus the two tubes and the reservoir, where the motion of the water took place, rested on supports independent of the other portions of the apparatus, and particularly of the two telescopes, and it was therefore the tubes only which could receive an accidental movement; but both reason and experience have shown, that the movements or bending of the tubes alone were without influence on the position of the fringes. The result of the observations made, is as follows :

When the water is set in motion its fringes are displaced, and according to the direction in which the water moves, the displacement takes place to the right or to the left.

The fringes are displaced towards the right, when the water flows from the observer in the tube situated on his right, and towards the observer in the tube situated on his left.

The fringes are displaced towards the left, when the direction of the current in each tube is opposite to that just indicated.

With a velocity of the water equal to two metres per second, the displacement is already very perceptible; with velocities of from four to seven metres, it becomes perfectly susceptible of being measured after having verified the existence of the phenomenon. I endeavored to ascertain its numerical value with as much exactitude as was possible, calling, a *simple* displacement, that which is produced when the water previously in repose was just set in motion, and a *double* displacement, that which is produced when the motion has just been changed to a contrary motion. We find by a mean deduced from nineteen observations, differing but slightly from each other, 0.23 for a simple displacement, which gives 0.46 for a double displacement, the width of the fringe being taken for unity. The velocity of the water was 7.069m. per second.

This result is afterwards compared with those which are deduced by calculation from the divers hypotheses relative to the ether.

On the supposition that the ether exists free, and independent of the motion of bodies, the displacement should be nothing.

On the hypothesis that the ether is united to the molecules of bodies, so as to partake of their motion, the calculation gives for the double displacement, the value of 0.92. The observation gave a number one-half smaller, or 0.46.

On the hypothesis that the ether is partially carried along, according to the theory of Fresnel, the calculation gives 0.40, that is to say, a number very approximately that which has been found by observation. And the difference between these two values would have been very probably still less, had it been found possible to introduce into the calculation of the velocity of the water, a correction necessarily neglected for want of data sufficiently precise, and depending on the unequal velocity of the different liquid filaments: in estimating the value of this correction in the most probable manner, we see that it tends to augment a little the theoretic number, and to approximate still more its value to the result of the observation.

An experiment similar to that just reported, had been previously made with air in motion, and I had ascertained that the motion of the air produces no sensible displacement in the fringes. Under the circumstances in which this experiment was made, and with the velocity of 25 metres per second, which was that given to the motion of the air, we find in the hypothesis, that the ether was carried along, that the double displacement should have been 0.82.

According to the hypothesis of Fresnel, the same displacement should have been but 0.000465, that is to say, altogether insensible. Thus the apparent immobility of the fringes, with the air in motion, is altogether in accordance with the theory of Fresnel.

It was after having verified this negative fact, and in the endeavor to explain the divers hypotheses relative to ether, in such a manner as to make them accord at the same time with the phenomenon of aberration, and with the experiment of M. Arago, that it appeared to me necessary to admit with Fresnel, that the motion of bodies occasions a change in the velocity of light, and that this change of velocity is greater or less for different mediums, according to the energy with which these mediums refract light, so that it is considerable in bodies of great refractive power, and very feeble in those which refract less, as the air.

It results from this, that if the fringes were not displaced when the light traversed air in motion, we should on the contrary have a very sensible displacement, in making the experiment with water whose index of refraction is much greater than that of air.

An experiment, for which we are indebted to M. Babinet, published in the ix. volume of the *Comptes Rendus de l'Academie des Sciences*, appeared to be in contradiction with the change of velocity in conformity with the law of Fresnel. But in considering the circumstances of this experiment, I have remarked the existence of a cause of compensation which should render insensible the effect due to the motion; this cause arises from the reflection which the light undergoes in this experiment; in fact, we can demonstrate, that when two rays have relative to each other a certain difference of phase, this difference is altered by the effect of the reflection from a mirror in motion; now in calculating separately the two effects in the experiment of M. Babinet, we find that they have values sensibly equal, and contrary signs.

This explanation renders still more probable the hypothesis of the change of velocity, and an experiment made in water in motion appears to me proper in every respect to decide the question with certainty.

The success of this experiment seems to me to necessitate the adoption of the hypothesis of Fresnel, or at least of the law which he has discovered to express the change of the velocity of light by the effect of the motion of bodies; for although, should this law be found true, it would be very strong proof in favor of the hypothesis of which it is but a consequence, perhaps the conception of Fresnel will appear so extraordinary, and in some respects so difficult to admit, that still further proofs, and a profound examination on the part of mathematicians may be demanded before adopting it as the expression of the reality of things.

For the Journal of the Franklin Institute.

Exposition of Foucault's Experiment. By J. S. BROWN.

In the exposition of Foucault's experiment, on page 354 of the Journal, an error was inadvertently inserted. It was there said that the deviation of the pendulum between 45° and 90° "is slower in the first, and faster in the last part of each half revolution." It should have read, slower in the first part of the first, and last part of the last, and faster in the last part of the first, and first part of the last half revolution.

I will here add, that between 0° and 45° , the deviation of the pendulum in the last half of each revolution of the earth is first *against the sun*,