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THE DRIFT OF THE ETHER

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OF all the terms used in science the ether is the most difficult to understand. For centuries its use has been confined to those engaged in teaching or in research. The great interest aroused by the theory of relativity and the extraordinary publicity which has been given to this most abtruse subject has made the word *ether* familiar everywhere. The thing itself is as great an enigma as ever.

The ether is that substance which is supposed to fill all space where there is no matter and also the spaces between the molecules, atoms and electrons within matter. The idea that space between the solid bodies was filled with some medium has long prevailed. To the ancient natural philosophers, the principle that "nature abhors a vacuum" was sufficient justification for supposing its existence, and another reason for believing in the reality of the ether was the notion that the planets were floating or swimming in a fluid.

However the only ether which has survived the older metaphysical conceptions is that one which we meet in Huygens' explanation of the propagation of light. Light is a form of energy which is transmitted from one point to another, from one place on the earth to another, or from the sun to the earth, or from the most distant parts of the universe. Energy can be transmitted in three ways: (1) There may be a direct material connection between the source and the point of delivery of the power. This method is illustrated by the lever, the line-shaft, the belt. (2)

There may be an actual transfer of matter, as illustrated by the rain, by a rifle bullet or any projectile. (3) Lastly, there may be a wave motion in a medium. If the smooth water surface in a pond is disturbed at one side, waves are set up in the water and the motion of the particles communicates itself to adjoining particles so that the disturbance is transmitted to the other side. If the air is disturbed by the stroke of a hammer the air in the region about the point of impact is compressed. The region of compression travels outward in all directions and delivers energy on our ear drums, which we interpret as sound. These three methods are the only ones we know for the transmission of power. Huygens' explanation of the propagation of light by waves is therefore based on analogy, and if there are waves we must invent a medium in which the waves exist. That medium is the ether.

The ether must have certain properties which may be made the subject of experiment. It readily permeates matter. If a tube more than thirty inches long, closed at one end, is filled with mercury and inverted with the open end in a basin of mercury, the height of the column will drop to about thirty inches, leaving a vacant space in the top of the tube. The vacant space is transparent and we must suppose is filled with the light carrying medium. If the tube is inclined, the mercury column rises to the top of the tube, apparently pushing out the ether which, however, immediately returns on restoring the tube to the upright position. The ether must be very non-resisting or mobile, for the planets and other heavenly bodies move through it at very great velocities and seem to suffer no apparent loss of speed. Even the comets, which are themselves probably one thousand times less dense than ordinary air, seem to suffer no retardation. The ether is probably quite elastic also, for it is shown in physics that the velocity with which a wave is propagated is equal to the square root of the elasticity divided by the density,

$$V=\sqrt{e/d}$$

where e is the elasticity, d the density, and V the velocity of light. The velocity of light has been measured and is very approximately 3×10^{10} cms. per second. Hence the elasticity of the ether multiplied by $1/d$ must equal 9×10^{20}. This relation is usually taken to mean that the density is very low rather than that e is large. From other considerations Lord Kelvin took the upper limit of the elasticity as 1/100, but the value is not known. The larger we make e the greater must be the density in order that the equation may hold. The ether is also very transparent, for the light comes down to us from the very distant astronomical bodies, such as the star clusters, without suffering absorption.

In 1725 an English astronomer, Bradley, made a discovery which was called the *aberration of light*. He discovered that every star's position was displaced forward in the sky in the direction in which the earth was moving. The following account of this discovery is taken from Grant's "History of Astronomy."

Up to about the year 1700 the facts revealed by the invention of the telescope and the discovery of gravitation established beyond all doubt the truth of the Copernican theory, but the absence of any observed change in the positions of the stars when observed from the opposite ends of the earth's orbit was a serious objection. Astronomers in various ages had attempted to observe this phenomenon but had failed. One of the methods which seemed to be best adapted for this purpose was that of observing stars whose zenith distance was small, since the effects arising from any uncertainty in the value of the refraction are thereby avoided. In 1725, Molyneux, an amateur astronomer, resolved to undertake a series of observations of γ Draconis, which passed very close to his zenith, and he had a large zenith sector erected at Kew, his place of residence. On the third of December, 1725, the instrument was employed for the first time in determining the position of the star. Similar observations were also made on the fifth, eleventh, and twelfth. It was deemed unnecessary to make any further observations until the season of the year should arrive when the earth was in the opposite side of its orbit. It was, therefore, more from curiosity than any other motive, according to his own statement, that Bradley, who was then at Kew, was induced to observe the star on the seventeenth of December. He found the position of the star to be somewhat more southerly than it appeared to have been early in December. Both Bradley and Molyneux suspected an error in the observations, and re-observed it on December the twentieth, when, to their great surprise, they discovered that it had advanced still farther south. This motion could not be due to parallax for it was in the wrong direction. The star continued to advance toward the south until the beginning of March, 1726, when it attained a distance of twenty seconds of arc from its original position, and in April it appeared to be returning north. In June, it again passed the meridian at the same distance from the zenith as it did in the beginning of December. It continued to move northward until September, when its displacement toward the north was as great as it had been toward the south in March. By December, 1926, it was again back in its original position, having performed its period of displacement in the same time that the earth revolved about the sun.

It was a considerable time before the explanation of the phenomenon was obtained, but at length the idea occurred to Bradley that the finite propagation of light combined with the motion of the earth in its orbit was the cause. We can understand the explanation with the least effort by an analogy. If you are out in a quiet rainstorm, when the rain is coming down in lines perpendicular to the surface of the earth, you will notice that as long as you are standing still you will see the drops of rain coming straight down, but that the moment you move forward they seem to come to meet you, and it is necessary to hold your umbrella somewhat in advance in order to keep the rain off. The similar thing is true in the case of light, only here the velocity of light is very large and the angle that the rays are deflected through is small. The analogy is not very complete because the rain drops are material bodies while we believe light to be waves in a medium. The same explanation will hold, however, if you consider the ether to be left behind by the earth or to remain at rest while the earth moves through it.

The hypothesis that the ether is not affected by the presence of matter introduces the greatest difficulty to the physicist on account of the phenomena of refraction. Refraction is explained on the wave theory by a diminished velocity for light in the refracting medium, which is hardly consistent with the view that the ether carries the light unaffected by the molecules of the substance. The wave theory of light had not been established at the time of the discovery of the aberration of light and, in fact, nearly one hundred years later, mathematicians like Laplace and Poisson, favoured the corpuscular theory. The discovery of interference by Young in 1800 and the investigations of Fresnel and others led to the abandonment of the corpusculary theory, and aberration had to be made consistent with the laws of refraction. Fresnel, who, with Arago, was the chief exponent of the wave theory, was led to the conclusion that the ether inside bodies moved with a fractional part of the bodies' motion, its velocity being represented by the expression

$$\frac{n^2-1}{n^2}\cdot V$$

where n is the index of refraction and V the velocity of light in free space. Fizeau, some twenty years later, using an apparatus which had in principle been suggested by Arago, tested this theoretical result and found it to be true. The experiments of Michelson and Morley, however, when they let a beam of light fall on a half-silvered surface where it divided, one half being made to pass through a tube in which there was a current of water flowing, the other part being made to pass through a tube whose water flowed in the opposite direction, showed that the velocity of light was not affected by the motion of the water. The experiment was performed in 1886, and at this time we think the difficulties connected with the explanation of the phenomena of aberration had been pretty well met.

To summarize, aberration demanded an ether which did not move with matter when the latter was suffering translation, and Michelson's experiment with the flowing water proved this. The experimental results of Fizeau, which showed a diminished velocity of light in media depending on the index of refraction and Fresnel's theoretical results that the molecules modified the ether in their immediate neighbourhood enabled the refraction phenomena to be explained. However, experiments had been made by Klinkerfues, and later by Airy, on the aberration of light in a telescope tube, filled with water and they showed no change in the coefficient of aberration. This result demanded that the ether be dragged along to a certain extent by the water in the tube.

A contradiction existed, therefore, between the aberration experiments of Airy and the flowing water experiments of Michelson and Morley. To test further the so-called drift of the ether, Michelson devised another experiment which was first performed in 1881 but was repeated much more carefully in 1887. It is usually known as *The* Michelson and Morley experiment. As the literature of the subject is not very recent, and is probably unavailable to the bulk of the readers of the JOURNAL, we give a short summary of their work which is taken from the *Philosophical Magazine* for December, 1887.

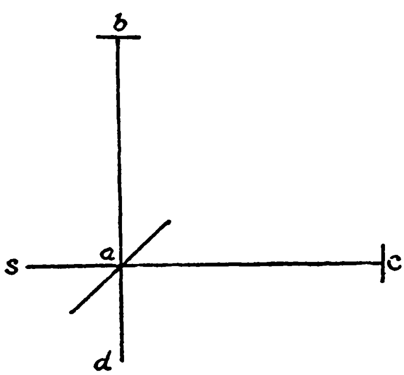

Fig. 1. Source Stationary.

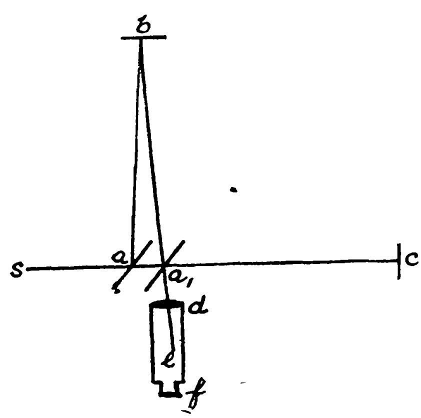

Fig. 2. Source moving.

Diagrams illustrating the path of the light.

In Figure 1, let *sa* be a ray of light which is incident upon a half-silvered surface inclined at 45°, so that the ray is partially reflected along *ab* and partially transmitted to *ac*. The two rays are returned by mirrors at *b* and *c*. The two returning beams are also reflected and refracted at *a* again, and if the paths *ab* and *ac* are equal the two rays interfere along *ad*.

Suppose the whole apparatus moves in the direction of *ac*, and that the ether remains at rest, the directions and distances traversed by the rays will be altered. The conditions of observation are represented in Figure 2. The ray which was reflected to *b* will have traversed the path aba_1 and the transmitted ray will have traversed the path aca_1.

Let V = velocity of light,
v = velocity of translation of the apparatus,
D = distance ab or ac Figure 1,
T = time light occupies to pass from a to c,
T_1 = time light occupies to pass from c to a_1.

Then

$$T=\frac{D}{V-v} \text{ and } T_1=\frac{D}{V+v}.$$

The whole time of going and coming is

$$T+T_1=2D\frac{V}{V^2-v^2},$$

and the distance travelled in this time is

$$\left[2D.\frac{V}{V^2-v^2}\right]V.$$

This may be written

$$2D\left[1-\frac{v^2}{V^2}\right]^{-1}=2D\left(1+\frac{v^2}{V^2}+\frac{v^4}{V^4}+\text{ etc.}\right)$$

Neglecting terms of the fourth order this reduces to

$$2D\left(1+\frac{v^2}{V^2}\right).$$

The length of the other path aba_1 may be readily computed from the fact that a_1 is to $2D$ as v is to V and hence $ab+ba_1$ is evidently $2D\left(1+\dfrac{v^2}{V^2}\right)^{1/2}$. This may be expanded as before, and, neglecting the higher powers, we get

$$2D\left(1+\frac{v^2}{2V^2}\right).$$

The difference in the paths of the refracted and reflected rays is therefore Dv^2/V^2, and if the whole apparatus be turned through 90°, the difference will be in the opposite direction.

A sketch of the apparatus used by Michelson and Morley is shown in Figure 3, while figure 4 gives a plan of the same apparatus. The optical parts proper of the apparatus rested on a square slab of stone about 6½ feet square and 12 inches thick. The stone in turn was fastened to a wooden annular ring which floated in a basin of mercury supported on a brick and cement pier. It will

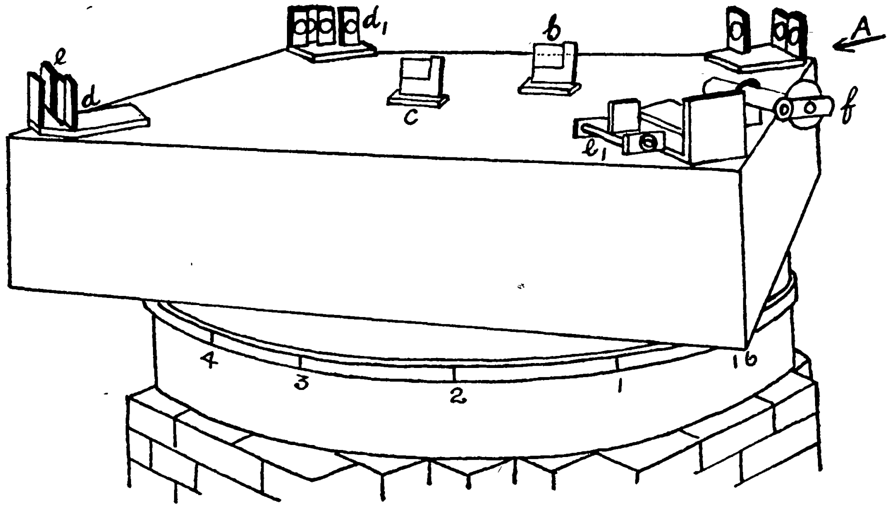

Fig. 3. Perspective view of Michelson's apparatus.

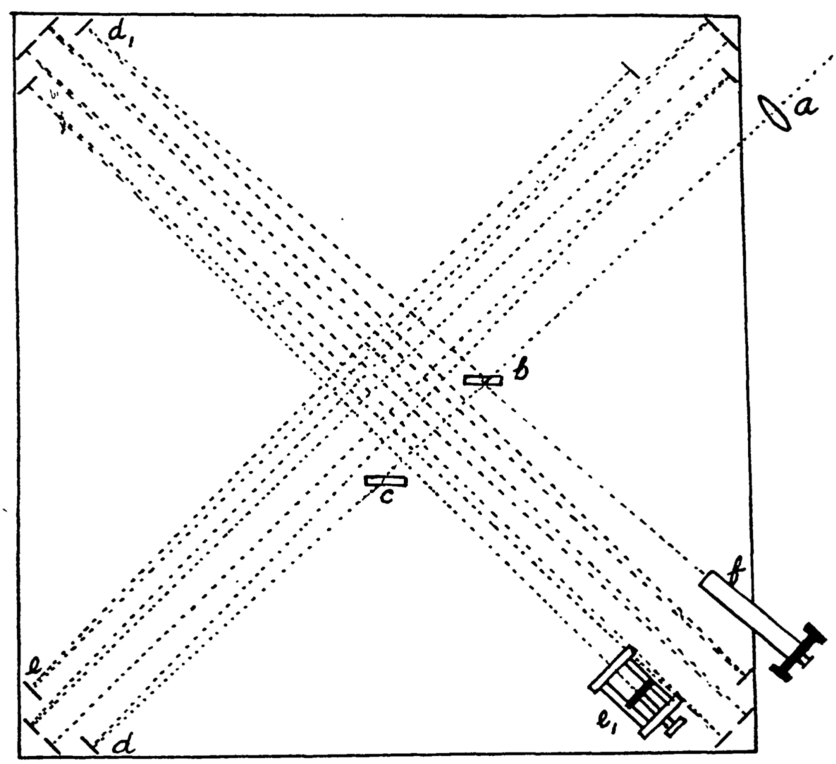

Fig. 4. Plan of apparatus, showing the path of the light in the interferometer.

be noticed that the formula for the difference in the two paths involves D, and in order to make this as large as possible a system of multiple reflections was employed. The light entered at A, passed through a lens and fell on b so as to be partly reflected to d_1 and partly transmitted to d; the two pencils followed the paths indicated in the figure, $bdedbf$ and bd_1e_1bf, respectively, and were observed by the telescope f. Both f and a revolve with the stone. The second mirror c was a plane piece of glass and was placed in the path of one of the pencils to compensate for the passage of the other through the same thickness of glass. The total length of path was about 37 feet or 11 metres. When the paths had been adjusted to equal length and the interference fringes were seen in the telescope, the observations were conducted as follows: Around the cast-iron trough were 16 marks, shown in Figure 3. The apparatus was revolved very slowly (one turn in 6 minutes) and after a few minutes the cross wire of the micrometer was set on the best of the interference fringes at the instant of passing one of the marks. The reading on the screw head was noted and a very slight and gradual impulse was given to maintain the rotation of the apparatus; on passing the second mark the same process was repeated and this was continued for 6 complete revolutions. It was found that by keeping the apparatus in slow uniform motion, the results were much more uniform than when the stone was brought to rest for every observation.

Readings were made on several days near noon and also at 6 p.m. Theory shows that if the velocity of the earth's motion entered with its full effect they should have observed a displacement of about 0.4 fringe. The actual motion of the earth in space is the resultant of its orbital motion and of the motion of translation of the solar system as a whole. The latter component being unknown it is impossible to predict any *expected* relative motion of the earth and ether. The interferometer is affected only by that component of the earth's total motion which lies in the horizontal plane of the apparatus. This plane is perpendicular to gravity at the location and is continually changing with respect to space as the earth rotates. Michelson and Morley announced their conclusion as follows: "Considering the motion of the earth in its orbit only . . . the observations show that the relative motion of the earth and the ether is probably less than one-sixth the earth's orbital velocity and certainly less than one-fourth." While the combination of the orbital velocity with the solar motion affects the predicted displacement, their conclusion seemed amply justified and was accepted as showing a negative result. The ether moves with the earth in its orbital velocity about the sun.

This result is not in harmony with the explanation of the aberration of light. To remove the difficulty several hypotheses were put forward, the most acceptable being probably that of Fitzgerald-Lorentz, who suggested that matter contracts in the direction of its motion. They supposed that the block of stone and the rest of the apparatus in the Michelson-Morley experiment shortened in the direction of translation by an amount sufficient to compensate for the expected increase of path due to the motion of the ether. This is not very hard to imagine when one realizes that the accepted view of matter makes it consist of very small particles, quite remote from one another, which might be crowded together slightly in the direction of motion. However, by using different substances for the support it was shown to be the same for two substances, and Lord Rayleigh suggested that any contraction should be accompanied by double refraction phenomena, which his experiments and those of Brace later failed to detect.

The next noteworthy experiment in the subject was made by Professor O. J. Lodge, in another attempt to detect the dragging effect of matter on the ether. The apparatus consisted of a pair of circular plates 3 feet in diameter. These plates were mounted with their planes parallel and 1 inch apart on a vertical axis, and were set spinning at as high a speed as they would safely stand without flying to pieces. If the ether in the space between the spinning discs is dragged around with them, then a pencil of light travelling around between the discs in the direction of motion would be expected to traverse the space with a greater velocity than a beam travelling in the opposite direction. To test this, a parallel beam of light was divided into two parts by a half-silvered mirror, and the two halves of this split beam were reflected by fixed mirrors, in such a way that they passed in opposite directions round and round the space between the spinning disks. The beams could thus be made to traverse a distance of 30 or 40 feet between the disks and then be allowed to enter a telescope, where they interfered and produced fringes. When due precautions were taken to avoid the disturbing effects of air currents thrown off by the disks, no indication of a shift was obtained. The experimental results were in harmony with what we would expect from the aberration of light but contradicted the Michelson-Morley experiment.

All the results so far obtained have been consistent in failing to detect the ether. They would be in harmony if the ether did not exist, but we would then be confronted with the problem of accounting for the propagation of light. Recent experiments seem to show that the ether has at last been detected and is a real thing.

Lord Kelvin expressed the conviction in 1900 at the International Congress of Physics that Michelson's experiment should be repeated with a more sensitive apparatus. Professor D. C. Miller, in collaboration with Professor Morley, constructed an interferometer about four times as sensitive as the one used in the first experiments, having a light path of 224 feet. The instrument was used in the basement of the Case School of Applied Science in Cleveland in 1904 and 1905. The result showed that the relative motion of the earth and ether was very small.

In the autumn of 1905 the interferometer was removed from the laboratory to a site in Cleveland at an altitude of 300 feet above Lake Erie and free from the obstruction of buildings. Here in 1905 and 1906 they got a positive effect of about 1/10 the earth's orbital velocity. They were not quite satisfied with the result, however, fearing that temperature changes in the instrument were the cause and they desired to test the thing at still higher elevations. The experiments were resumed in March and April, 1921, at the Mount Wilson Observatory in California at 6000 feet altitude.

At the Mount Wilson station about 5000 single measures of the ether drift were made at various times of day and night. The apparatus being the same as used in 1904 and in principle the same as that of the Michelson-Morley experiment. Each observation gave, for a specified time, the magnitude of the displacement of the interference fringes, together with the azimuth of the line of sight in which the displacement was a maximum. Since the light in the interferometer travelled along one arm and back again the observations gave only the line in which the drift occurred but not the sign.

Figure 5 shows the observations of April, 1921. Here the arrows indicate the observed direction and the magnitude of the drift, the arrows being located around a circle at points corresponding to the sidereal times of observation. The observations were next repeated when the metal parts had been shielded from temperature changes by cork, and the results were unaltered.

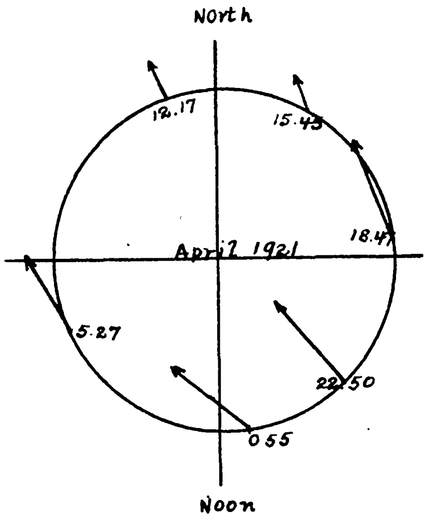

Fig. 5.

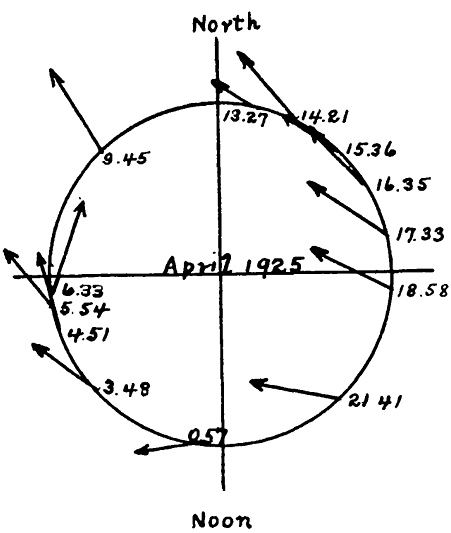

Fig. 6.

The arrows indicate the observed relative drift of the observer and the ether.

As a next trial the instrument was partially rebuilt, getting rid of any metal parts which might have a magnetic effect; but the result of 900 observations showed an ether drift of exactly the same direction and amount as previously obtained. At the same time many variations of conditions were tried, such as reversing the direction of rotation, making the rotation fast or slow, putting the frame under an added load, with the float level or tilted with the assistant walking around near or far from the apparatus while the measures were being made. The results were unchanged.

As a further test of the reliability of the apparatus ti was dismounted and taken to Cleveland, and many trials made there to determine the effect which the conditions of observation had on the result. Notable among these were those to test the effect of inequalities in temperature. Electric heaters were placed in close proximity to the apparatus, and while they caused a slow drift of the fringes they did not produce a periodic shift. The net result of all these experiments was to confirm in a very satisfactory manner the result obtained nearly forty years earlier, namely, that near the surface of the earth there was no relative drift of the earth and the ether.

In 1924 the apparatus was again taken to Mount Wilson to repeat the experiment. In 1921, the apparatus had been located on the very edge of a deep canyon and it was feared that air currents

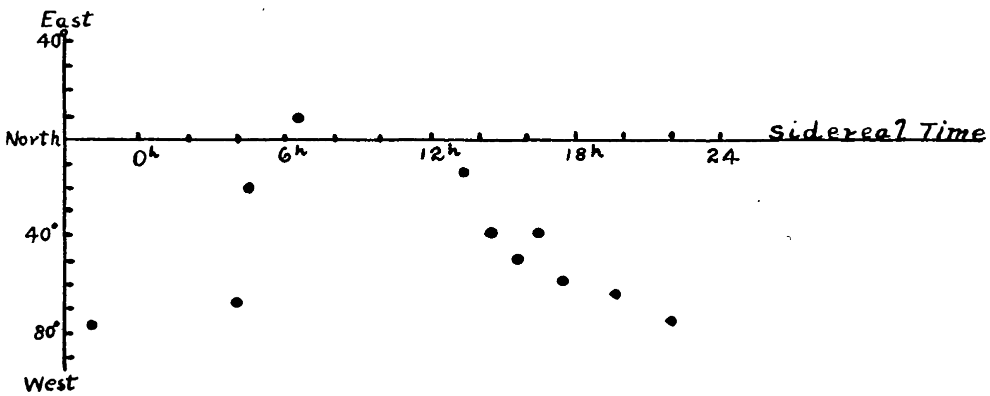

Fig. 7. Diagram showing the direction of the drift with respect to the points of the compass at various sidereal times.

might have produced a disturbance. A new site was chosen and the interferometer house erected with its orientation as regards the ridge changed 90° from that of 1921. The results of 275 measures are shown in Figure 6. The corresponding ether drift is consistent in direction and magnitude with the results obtained before and shown in Figure 5.

There is a specific relation for a given latitude between the observed azimuth of drift and the sidereal time of observation. Observations at different sidereal times should show different azimuths and all observations at the same sidereal time should show the same azimuth. Sixteen hundred observations were combined into eleven sets at various sidereal times, with the result shown in Figure 7. The ordinates of the graph are azimuths and the abscissae sidereal times. The points lie on a curve of the kind that would correspond to some definite direction and velocity of ether drift.

Summing up the results of Miller's work at Mount Wilson during the years 1921 to 1925 we are led to the conclusion that there is a drift of the ether of about 1/3 the orbital velocity of the earth, and a drift which varies with the altitude is also suggested. We have now positive evidence of a medium which carries the light, and that the velocity of light relative to the earth varies when the earth moves in the medium. It is true that a satisfactory explanation of aberration cannot be given and that the results obtained with the water-filled telescope are also unexplained. The writer of this article is not well enough versed with the theory of relativity to say just what effect there will be on that doctrine, but it would appear that some of the premises must be altered, since the basic experiment which suggested it is shown to have different results from those formerly held to be true.

Readers will remember that one of the predicted results of the relativity theory was the shift of the stars near the sun due to the gravitational field. The shift was shown to be there by the English astronomers in 1919 and confirmed at subsequent eclipses very strikingly. We have to find an explanation for this shift.

The whole study of the drift of the ether is a beautiful example of the scientific method of research. In the beginning there were the two theories, the corpuscular and the wave theory. These suggested experiments which led to new discoveries, and each experiment and research was suggested and based on results obtained previously. It does not matter so much whether the wave theory, the corpuscular theory or the theory of relativity represents a reality, for at least all have been productive in suggesting lines of research which have led to discoveries. There is a great satisfaction in harmonizing the results of experiments by some general law. Science is not yet in a position to formulate this general law for the relation of the light to the ether, but at the rate progress is being made something definite should evolve in the years soon to come.