Ether-Drift Experiments at Mount Wilson.

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THE Michelson-Morley experiment for determining the relative motion of the earth and the luminiferous ether, the "ether-drift experiment," was first performed in Cleveland in the year 1887, by Prof. Albert A. Michelson and the late Prof. Edward W. Morley. The theory of the experiment and a description of the apparatus was published in the *Philosophical Magazine* for 1887, and has been repeated in many text-books since that time. They announced their conclusions 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." (That is, it is less than 7·5 kilometres per second.) This result was considered by many as a null result, often called a negative result, and by some was thought to throw grave doubts upon the validity of the hypothesis of the luminiferous ether.

At the International Congress of Physics, held in Paris in 1900, Lord Kelvin expressed the conviction that the experiment should be repeated with a more sensitive apparatus. The present writer, in collaboration with Prof. Morley, constructed an interferometer about four times as sensitive as that used in the first experiments, having a light path of 224 feet, equal to about 150,000,000 wave-lengths. In this instrument a relative velocity of the earth and ether equal to the earth's orbital velocity would be indicated by a displacement of the interference fringes equal to 1·5 fringes. This apparatus was used in the basement of the Physical Laboratory of Case School of Applied Science in Cleveland, observations being made in 1904 and 1905. The result of these observations was published in the *Philosophical Magazine* for May 1905, as follows: "We may, therefore, declare that the experiment shows that if the ether near the apparatus did not move with it, the difference in velocity was less than 3·5 kilometres per second unless the effect on the materials annulled the effect sought. Some have thought that this experiment only proves that the ether in a certain basement-room is carried along with it. We desire, therefore, to place the apparatus on a hill to see if an effect can be there detected."

In the autumn of 1905 Morley and Miller removed this interferometer from the college laboratory to a site on Euclid Heights, Cleveland, at an altitude of 300 feet above Lake Erie and free from obstruction of buildings. Five preliminary observations were made which gave indication of a positive effect as of an ether-drift of about one-tenth of the then expected drift. We were compelled to discontinue these experiments by circumstances beyond our control, before any definite results could be obtained.

The indication of a small positive effect made it seem necessary to continue the experiments, but it was thought desirable that further observations should be carried out at a much higher altitude. Prof. Morley retired from active work in 1906 and the continuance of the observations was long delayed. The suitable opportunity for continuing the experiments came in 1921, and upon the invitation of Prof. George E. Hale, Director of the Mount Wilson Observatory in California, the interferometer which had been used in 1905 was remounted at the Mount Wilson Observatory. Four distinct groups of observations have now been made in this location: in March and April 1921, in November and December 1921, in August and September 1924, and in March and April 1925. The first observations at this Observatory gave a definite, positive result considerably larger than that previously obtained in Cleveland, being equal to about one-third of the earth's orbital velocity.

On the simple theory of the ether-drift experiment, it is presumed that the system of interference fringes which is observed will suffer a periodic displacement as the interferometer is rotated in the horizontal plane, this displacement being proportional to the relative motion of the earth and the ether. The rotation of the earth on its axis causes the plane of the interferometer to move as though it were on the surface of a cone the axis of which coincides with that of the earth, and thus to take many different space orientations. It is only that component of the actual drift which lies in the horizontal plane of the interferometer at the moment of observation which can be observed. Therefore, the *apparent* azimuth and magnitude of the drift should change with the time of observation. A drift perpendicular to the plane of the interferometer will produce no effect whatever; it is quite possible that this condition may occur at certain times of the year.

It was suggested that the small observed effect might be due to magnetism acting on the steel frame of the interferometer, or that it might be due to radiant heat or other instrumental disturbances. The trying out of the various suggestions has involved continuous experimentation during the last four years, in which time every suspected cause of disturbance has been investigated, and it has been shown that none of these causes is responsible for the observed displacement.

In the summer of 1921 the steel frame of the interferometer was dismounted and a base of one piece of concrete reinforced with brass was cast in place on the mercury float. All the metal parts were made of aluminium or brass; thus the entire apparatus was free from magnetic effects and the possible effects due to heat were much reduced. In December 1921, 42 sets of observations consisting of 900 single measures of the drift were made with the non-magnetic interferometer. These show a positive effect as of an ether-drift which is entirely consistent with the observations of April 1921. Many variations of incidental conditions were tried at this epoch. Observations were made with rotations of the interferometer clockwise and counter-clockwise, with a rapid rotation and a very slow rotation, with the interferometer extremely out of level, due to the loading of the float on one side. Many variations of procedure in observing and recording were tried. The results of the observations were not affected by any of these changes.

The entire apparatus was returned to the laboratory

in Cleveland. During the years 1922 and 1923, many trials were made under various conditions which could be controlled and with many modifications of the arrangements of parts of the apparatus. An arrangement of prisms and mirrors was made so that the source of light could be placed outside the observing room, and a further complication of mirrors was tried for observing the fringes from a stationary telescope. Methods of photographic registration by means of a motion picture camera were tried. Various sources of light were employed, including sunlight and the electric arc. Finally, an arrangement was perfected for making observations with an astronomical telescope having an objective of five inches aperture and a magnification of fifty diameters. The source of light adopted was a large acetylene lamp of the kind commonly used for automobile headlights. An extended series of experiments was made to determine the influence of inequality of temperature and of radiant heat, and various insulating covers were provided for the base of the interferometer and for the light path. These experiments proved that under the conditions of actual observation, the periodic displacement could not possibly be produced by temperature effects. An extended investigation in the laboratory demonstrated that the full-period effect mentioned in the preliminary report on the Mount Wilson observations is a necessary geometrical result of the adjustment of mirrors when fringes of finite width are used, and that the effect vanishes only for fringes of infinite width, as is presumed in the simple theory of the experiment.

In July 1924 the interferometer was taken again to Mount Wilson and mounted on a new site where the temperature conditions were more favourable than those of 1921. The interferometer house was also mounted with a different orientation. Again the observations showed a definite positive effect corresponding to the observations previously made at Mount Wilson. The observations on Mount Wilson were resumed in March 1925, and continued until about the middle of April, during which time 1600 measures of the drift were made. Again many variations in detail of arrangement of parts and in methods of observing were made without in any way altering the result. Throughout the latter epoch of observations the conditions were exceptionally good. The observations of April 1925 give results almost identical with those of April 1921, notwithstanding that the interferometer had been rebuilt and that a different system of illumination and different methods of observation were employed, and that it was mounted on a new site in a house differently oriented.

The interferometer readings being plotted, give directly by harmonic analysis the azimuth and magnitude of the ether-drift. There are no corrections of any kind to be applied to the observed values. In the work so far, every reading of the drift made at Mount Wilson has been included at its full value; no observation has been omitted because it seemed to be poor, and no "weights" have been applied to reduce the influence on the result, since no assumption has been made as to the expected result. It may be added that while the readings are being made, neither the observer nor the recorder can form the slightest idea as to whether any periodicity is present, much less as to the direction or amount of such periodicity.

The ether-drift experiments at Mount Wilson during the last four years, 1921 to 1925, consisting of about 5000 single measures of the drift, lead to the conclusion that there is a positive displacement of the interference fringes, such as would be produced by a relative motion of the earth and the ether at this Observatory, of approximately ten kilometres per second, being about one-third of the orbital velocity of the earth. By comparison with the earlier Cleveland observations, this suggests a partial drag of the ether by the earth, which decreases with altitude. A more extended account of these observations is given in the Proceedings of the National Academy of Sciences for June 1925.

Dr. Ludwik Silberstein, in his letter to NATURE of May 23, has pointed out that these results, indicating a partial drag of the ether by the earth, "are easily explicable by means of the Stokes' ether concept, as modified by Planck and Lorentz," as discussed in a paper by Silberstein in the *Philosophical Magazine* for February 1920.

The final test of these observations is whether they lead to a rational and wholly consistent indication of a constant motion of the solar system in space, combined with the orbital motion of the earth and the daily rotation on its axis. 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 for a given epoch. It is believed that a reconsideration of the Cleveland observations, from this point of view, will show that they are in accordance with this presumption, and will lead to the conclusion that the Michelson-Morley experiment does not and probably never has given a true zero result. A complete calculation of the observations, now in progress, together with further experiments to be made in the immediate future, should give definite indications regarding the absolute motion of the solar system in space.

The Science Exhibition at Wembley.

THE Science Exhibition arranged by a Committee of the Royal Society in the Government Pavilion at Wembley represents a great advance on the similar exhibition held last year, particularly as regards the section devoted to physics. The space available has been considerably extended and the equipment of the demonstration benches is much more adequate. Perhaps the most striking advance, however, is the admirably systematic manner in which it is now possible to present the exhibits, for these have been arranged on an underlying plan which gives unity to the whole and converts a collection of miscellaneous experiments into an orderly sequence of demonstrations, which are not only striking in themselves but also calculated to give visitors a very fair impression of the nature of modern physics and the scope of the problems to which it addresses itself. The key to this part of the exhibition is to be found in an enormous chart, some 24 ft. long,