Astron. Nachr., 303 (1982) 1, 3–5

Michelson in Potsdam

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(Received 1981 June 1)

It is a great pleasure to send greetings to the *"Michelson Colloquium"* in Potsdam to celebrate the experiment he performed there in April 1881 on the aether-drift problem that had occupied the attention of physicists since the revival of the wave-theory of light at the beginning of the 19th Century. This experiment was the first in which the famous *Michelson Interferometer* was used, it having been specifically devised for this work. I have thought a great deal about how Michelson came to invent his interferometer, but like all questions in the history of science the essential steps can never be clearly known. But there are some hints along the way to his great invention.

During the period before Michelson travelled to Europe for study and research in 1880–1882, he had worked with the great astronomer, Simon Newcomb, in Washington. They had made measurements of the speed of light in air employing a method which Newcomb had devised and also one of Michelson's which incorporated an important improvement on the earlier rotating mirror method of J. L. Foucault. This joint work gave the best determination up to that time and did much to make Michelson known to physicists. But none of this work employed optical interference methods and so can hardly be viewed as a forerunner of the Michelson Interferometer. The only hint of Michelson's interest in wave optics at that time is in a short paper presented on April 24, 1880 to the Philosophical Society of Washington on "The Modifications suffered by Light in Passing Through a Very Narrow Slit". His description of the diffraction, polarization and color effects is very accurate, but there is no suggestion of the major role that diffraction and interference phenomena were to play in his later work.

However, there is a very direct connection between Michelson's work and a letter received a year earlier on March 19, 1879 from James Clerk Maxwell addressed to David Peck Todd at the National Almanac Office where Michelson worked with Newcomb. Maxwell had enquired whether observations on the satellites of Jupiter could be made with sufficient precision to extend the velocity of light determinations of Roemer by making them at times near dawn and dusk to reveal changes in the speed of light caused by the earth's motion through the aether. Maxwell explained that his proposed method would only require accuracy to the order (v/c), the ratio of the earth's speed to that of light, whereas all purely terrestrial aether-drift experiments demanded the much greater sensitivity of $(v/c)^2$, and that no apparatus then existed capable of this severe requirement.

But this assertion of Maxwell's was the challenge that the young Michelson accepted and which led to the invention of his interferometer! His paper on light passing through a narrow slit seems to have been the first step on this journey. Another was that at about this time Newcomb interested Mr. Alexander Graham Bell in providing Michelson with funds ($ 500) to carry on his optical experiments in Europe. However, there is no surviving record of what Michelson may have explained to Bell about his plans.

When Michelson arrived at Professor H. von Helmholtz's laboratory in Berlin in the fall of 1880 his work on the aether-drift experiment progressed rapidly. Professor von Helmholtz was world famous for his contributions to physiological optics and his laboratory was a renowned center for optical research, and this environment no doubt was an important factor in Michelson's progress. He soon commissioned the firm of Schmidt and Haensch to construct his first interferometer. When the proposed experiment was explained to Helmholtz, he warned Michelson that temperature variations could cause serious problems in the use of so sensitive an apparatus. Michelson seems to have surmounted this difficulty but soon found that vibration from street traffic and other causes in Berlin made the interference fringes too unsteady for accurate observations.

At this juncture, Professor von Helmholtz arranged with Professor H. C. Vogel, Director of the Astrophysikalisches Observatorium in Potsdam for the work to be carried on there. After preliminary tests and modifications of the instrument, it was found that the circular basement room under the equatorial telescope provided the necessary stable conditions for reliable observations. Michelson made observations on the interference fringes with the apparatus set at each of the 8 points of the compass. He had calculated that the effect of the earth's motion through the aether as the interferometer was moved would result in a maximum shift "to be not far from one tenth [later corrected by H. A. Lorentz and others to half this value] the distance between the fringes".

Michelson analyzed his data in several ways searching for the expected shift in the interference pattern. In his own words: "The interpretation of these results is that there is no displacement of the inferference bands. The result of the hypothesis of a stationary [Fresnel] ether is thus shown to be incorrect ... This conclusion directly contradicts the explanation ... hitherto generally accepted ... that the earth moves through the ether, the latter remaining at rest".

MICHELSON himself and the physics community generally did not view this result with enthusiasm. In fact in his published paper MICHELSON sought to retain the aether by citing a theory of G. G. STOKES proposing that the earth would drag the aether along in its motion and thus eliminate the relative motion of earth and aether sought by the experiment. It was only the stationary aether hypothesis of FRESNEL that he claimed to have disproved — not the existence of the aether itself.

We now know that the Potsdam experiment was correct. But as the experimental uncertainties were nearly as large as the expected effect, there were serious doubts about accepting the results. The leading theorists of the time: H. A. LORENTZ, G. F. FITZGERALD, Sir JOSEPH LARMOR, Lord RAYLEIGH, and Lord KELVIN were all of the school that believed an aether was essential for the propagation of light as a wave motion in space. As an example of this viewpoint, H. A. LORENTZ wrote to Lord RAYLEIGH asking, "Is there not some feature in the explanation of Mr. MICHELSON's experiment that has been overlooked?" Even as late as 1903 MICHELSON would state in his book "Light Waves and Their Uses", "The experiment is to me historically interesting, because it was for the solution of this problem [aether-drift] that the interferometer was devised. I think it will be admitted that the problem, by leading to the invention of the interferometer, more than compensated for the fact that this particular experiment gave a negative result".

The physicists who treated MICHELSON's Potsdam experiment in the most constructive way were H. A. LORENTZ in Leiden and G. F. FITZGERALD in Dublin. FITZGERALD proposed and LORENTZ gave a theoretical explanation ever since known as the FITZGERALD-LORENTZ contraction (or simply the LORENTZ contraction) to explain MICHELSON's null result. Simply stated they proposed that the dimensions of the apparatus were altered (contracted) in the direction parallel to the motion by just the amount to produce the observed negative finding. LORENTZ continued to develop this theory — the Electron Theory — in a series of papers culminating in one in 1904 which predicted that all attempts to observe an aether-drift in laboratory experiments should yield null results like those found by MICHELSON in Potsdam and in later aether-drift experiments.

But meanwhile, doubts had continued to exist about MICHELSON's Potsdam experiment. MICHELSON came to Cleveland in September 1882 as the first Professor of Physics at the newly established Case School of Applied Science, now Case Institute of Technology. His first researches there were precise measurements of the speed of light in air, in water, and in carbon disulphide. These added greatly to his reputation for the first gave a value for the speed of light that was not improved upon until his own Mt. Wilson measurements in 1927. The speed of light in water accurately confirmed the value predicted by the wave theory of light; while his measurements in CS_2 at first seemed anomalous, but were soon explained by Lord RAYLEIGH as due to the expected difference between wave and group velocities in a highly dispersive medium. During his first two years at Case, MICHELSON showed very little interest in the aether-drift problem.

But in October of 1884 MICHELSON and EDWARD W. MORLEY, Professor of Chemistry at Western Reserve University, attended the Baltimore Lectures of Lord KELVIN (then Sir WILLIAM THOMSON) at the John Hopkins University. Lord RAYLEIGH also attended some of these lectures and both he and KELVIN strongly urged MICHELSON to repeat his aether-drift experiment. With this urging and with Professor MORLEY's agreement to collaborate, he agreed to make a new trial.

But as an essential preliminary to the main experiment they made a very precise repetition (using a special form of the MICHELSON interferometer) of the H. FIZEAU experiment of 1851 which had shown that the speed of light in moving water is changed not by the full amount of the motion, but by only a fraction (less than half) given by the FRESNEL drag coefficient. The reason for repeating this experiment (their result was much more precise than FIZEAU's) is the following. The null result of the Potsdam experiment had been explained by MICHELSON as due to the dragging of the aether by the earth (and the interferometer). If this drag were complete then there would be no relative motion to observe. But if the drag were only a fraction of the motion then there should be a positive result (reduced by about one-half), and the experiment should be successful.

The result found by MICHELSON and MORLEY confirmed FIZEAU's discovery of a partial drag and so they proceeded with their repetition of the Potsdam experiment. The interferometer used in the Cleveland work had several major improvements over the one used in Potsdam. The optical paths in the apparatus were increased by about a factor of 10 by using multiple reflections of the light beams in the two arms of the interferometer. The optical parts were mounted on a heavy sandstone slab (5 ft by 5 ft $\times$ 1.5 ft) which in turn was floated on mercury, thus greatly reducing the effect of external vibrations and strains in the apparatus. With these improvements the expected 0.4 of a fringe displacement as the interferometer slowly rotated could have been measured with certainty. But the Cleveland result obtained in July 1887 was this:

$$\text{Maximum Fringe Shift} = 0.01 \pm 0.01\,.$$

Today we view this as a triumphant confirmation of the Potsdam experiment, but in 1887 disappointment with the null result was again the rule. MICHELSON and MORLEY had planned to repeat their observations each month during a full year, to guard against the possible cancellation at any one epoch of the earth's motion with that of the whole solar system. But instead they simply abandoned the experiment and turned to their great work for Standardizing the Meter in terms of Light Waves.

But now there could no longer be valid doubts about the Potsdam experiment, and a serious examination of the foundations of theoretical physics began. Many people contributed to the final result. Chief among those for many years were H. A. LORENTZ, HENRI POINCARÉ, and Sir JOSEPH LARMOR. Their work provided the basis for the advances that finally led to the Special Theory of Relativity of ALBERT EINSTEIN in 1905. Both the Potsdam and

Cleveland experiments were important for this great advance in the description of the workings of nature. Professor EINSTEIN told me (in 1950) that he also discussed the MICHELSON and MICHELSON-MORLEY experiments many times with H. A. LORENTZ after 1905 when he was developing his General Theory of Relativity.

So we are honored to send greetings and best wishes from Cleveland to Potsdam for the Centennial celebration marking the great pioneer experiment of ALBERT MICHELSON with his interferometer.

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