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History and Education of the Albert A. Michelson Exhibition Developed at the Occasion of the Einstein Centenary Berlin 1979 and the Michelson Colloquium Potsdam 1981*

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Abstract

Michelson's technical invention of his interferometer and his performance of the first experiment with the interferometer was a milestone in the history of physics. This paper reviews the history of the Michelson experiment, invented, and performed for the first time at the Astrophysical Observatory Potsdam in 1881. The paper draws attention to the International Michelson Colloquium, held from April 27 to April 30, 1981, in Potsdam (Germany) (Treder, 1979, 1982). This paper is an attempt to reconsider a scientific event organized more than 40 years ago, as the follow-up to Einstein's Centenary, celebrated from 28 February to 2 March 1979 in Berlin (Germany) (Treder, 1979; Bleyer et al., 1979), for Michelson's experiment done more than 140 years ago. Issues in history, education, and research still pursued today with reference to Michelson's experiment are highlighted. For the first time letters from Max Born and Helen Dukas to be of interest for the relation of Einstein and Michelson is part of this paper.

Keywords

History, Education, Research, Einstein Centenary, Berlin 1979, Michelson Colloquium, Potsdam 1981

1. Einstein Centenary 1979 and Michelson Colloquium 1981

In his famous experiment in 1881 (Consoli & Pluchino, 2019) in the eastern basement of the Astrophysical Observatory Potsdam (**Figure 1**), Michelson in-

*The paper is dedicated to the 200th Anniversary of the oldest astronomical journal, Astronomische Nachrichten, founded by H. C. Schumacher in 1821 and the150th Anniversary of the establishment of the Astrophysikalisches Observatorium Potsdam (AOP) on 1st July 1874.

tended to demonstrate that his interferometer (Lucas, 2023) was able to satisfy the task to verify the effect of the motion of the Earth on the propagation of light. It was expected that the velocity of light is composed of that of the Earth. The speed of the light should exceed the speed of the light which traverses the orbit by 30 km/s. In that case, the distance of the two images would depend on the orientation of the interferometer. The interferometer did not find any difference in the two velocities. Michelson had to conclude a so-called "null result" that the propagation of light was determined by the walls, just as the propagation of sound in the air of the basement room had to relate to the walls. Michelson's interferometer result is a paradigmatic example of a null result in physics, a result may be said to be null when it not detected by the measuring device employed. The value returned by the measuring instrumentation is "zero". It is very rarely the case that an unadulterated zero result will occur since there will almost always be measurable, small interfering causes and resultant noise at play. Thus, a better description of a null result is that it is "zero" plus small though annoying residual variations. Today, Michelson's original experiment and its many repetitions are considered as a venerable well understood historical chapter for which, at least from a physical point of view, there is nothing more to refine or clarify. Though, this is not necessarily true, and this was also the subject of the Michelson Colloquium, and it remains the subject until today.

Figure 1. Main building of the Astrophysical Observatory Potsdam, Telegrafenberg.

2. Astrophysical Observatory Potsdam 1881

From April 27 to April 30, 1981, an international colloquium in honour of the physicist and first American Nobel laureate Albert Abraham Michelson (1852-1931) and his scientific work took place in Potsdam, Germany. The occasion for this Michelson Colloquium at the Astrophysical Observatory Potsdam was the centenary of the year in which the famous Michelson experiment was performed for the first time in the Astrophysical Observatory Potsdam (Haubold & John, 1981, 1982; Goldberg & Stuewer, 1988).

The Michelson Colloquium was held under the auspices of the Academy of Sciences of the GDR (Central Institute for Astrophysics); its arrangement at the Astrophysical Observatory Potsdam was sponsored by the Einstein Laboratory for Theoretical Physics, Caputh, the Physical Society of the GDR, Berlin, and the

Department of Physics of the Humboldt University, Berlin.

About one hundred years ago, in April 1881, Michelson performed for the first time his interferometer experiment to determine the velocity of the Earth relative to the hypothetical luminiferous aether—an experiment which entered history of physics and astronomy (Holton, 1988). The null result of the experiment, rejecting the aether hypothesis of Fresnel, turned out to be fundamental for the evolution of physics, as a landmark on the way of the genesis of Einstein's theory of relativity. The incitement for undertaking such a crucial experiment Michelson had found in ideas of J.C. Maxwell. The interferometer by which he carried out his experiment and which he later used in various investigations in physics and astronomy, Michelson invented during a visit to Europe, beginning at the end of 1880 (**Figures 2-6**).

Figure 2. Panels in the Rotunda of the main building of the Astrophysical Observatory Potsdam showing historical astronomical instruments used in the observatory after its foundation in 1874.

Figure 3. U. Bleyer and HJH in conversation with Konrad Wachsmann (USA; 1901-1980) during his visit of the 1979 Michelson exhibition in the main building of the Astrophysical Observatory Potsdam. He developed an industrial prefabricated wood construction system for single family houses in 1925 whose most famous product is the summer house of Albert Einstein (1879-1955) in Caputh/Potsdam.

Figure 4. Panels in the Michelson basement in the east dome of the Astrophysical Observatory Potsdam illustrating Michelson's travel in visiting scientific institutions in Europe around 1881.

Figure 5. HJH welcoming Ilya Frank during the 1979 Einstein Centenary celebrations for his visit of the 1979 Michelson exhibition in the main building of the Astrophysical Observatory Potsdam. Ilya Mikhailovich Frank (Russia; 1908-1990) was a Soviet physicist who received the 1958 Nobel Prize for Physics, jointly with P.A. Cherenkov and I.Y. Tamm. He received the award for his work in explaining the phenomenon of Cherenkov radiation which, like Michelson's interferometer, plays an continuing important role in experiments in natural sciences (today including the solar neutrino experiments with Kamiokande, SuperKamiokande in Japan, and Sudbury Neutrino Experiment in Canada).

The device was made by the optical firm Schmidt and Haensch in Berlin (Kuchejda, 2014) and the experiment was prepared at the Physical Institute of the Friedrich Wilhelms University of Berlin (later Humboldt University), located at the Reichstagsufer and lead by Hermann von Helmholtz (Jaffe, 1960; Cahan, 2004). However, because of the sensitivity of the instrument against vibrations, one had to look for a place of lower vibration level. The memorable experiment was finally realised in the Astrophysical Observatory Potsdam, not far from Berlin. As Michelson later mentioned, the then director of the Observatory, H.C. Vogel, was at once interested in the experiment. The whole experimental set up was placed in the basement of the east dome of the main building of the Observatory (Figure 6).

Figure 6. Reconstruction of the original Michelson interferometer located in the Michelson basement. Today the use of this Michelson interferometer is demonstrated by Dierk-Ekkehard Liebscher (center of the photo) to visitors of the Astrophysical Observatory Potsdam.

2.1. WEMPE: Topic History Michelson Experiment Berlin

For nearly two years Michelson roamed the universities of Germany and France. He absorbed all the knowledge he could from the great men of European physics. He attended the lectures of Hermann von Helmholtz, the world-famous professor of theoretical physics at the University of Berlin, and did some laboratory work there. He drew plans for his interferometer and turned them over to the instrument company Schmidt + Haensch in Berlin for construction. Michelson made his first trial at the laboratory of Hermann von Helmholtz, at the University of Berlin (Wempe, 1906-1980; Wempe, 1975). They had discussed the experiment at length. Helmholtz stressed the difficulties of keeping a constant temperature. Further, even though the interferometer was set on a solid-stone pier in Helmholtz's laboratory, vibrations from the Berlin traffic disturbed the observations, at night as well as in the daytime (Reingold, 1966). In April, Michelson had the apparatus dismantled and taken to the Astrophysical Observatory Potsdam for another trial. There, in a hollow space in the brick pier below an astronomical telescope, Michelsons acutely sensitive instrument finally appeared to give a clear result. To his amazement, the experiment produced a zero effect. Michelson could find no drag on the transmission of light in any direction. He detected only the slightest shift in the interference fringes. Both halves of the split single beam of light were returning at virtually the same instant. He recorded his findings in the August 1881 (5) issue of the American Journal of Physics under the title "The Relative Motion of the Earth and the Luminiferous

Ether". His conclusion was short and unmistakable "The hypothesis of a stationary ether is erroneous" he wrote.

2.2. LIEBSCHER: Topic Education Michelson Experiment

For educational purposes, D.-E. Liebscher (Liebscher, 2023) discussed the Michelson experiment and its family of misunderstandings. There are only a few experiments in physics which are cited by name in textbooks of general education. The Michelson experiment is the most known because it is rated to be the foundation of the theory of relativity. In general, it is known that Michelson intended to measure the headwind in the ether which is felt by the Earth on its orbit around the Sun. One knows that the theory of relativity is referring to it because the expected headwind was not found. Again, in general, one will not have been informed why one needs an ether at all, why the headwind was expected in a basement, and why this all has to do with relativity. Why did one need a luminiferous aether at all? With superposition of velocities through addition, for observers in relative motion, at most one observes the propagation of a wave as isotropic (independent of its direction). An observer can calculate velocity by evaluation of the anisotropy he observes. Galilei argued that any velocity is relative to some object, but where is the object here? It is an (the) aether. In this aether one expects the light to propagate isotropic. For the moment, Galileo's postulate of relativity is saved by the aether.

Is the existence of an aether equivalent to an absolute space or absolute rest? This is a matter of wording. The notion of absolute space is at first pure invention. In order to identify position, orientation, time, and velocity one has to refer to other material objects, not to any virtual space. This is the summary of Galileo, and the reason for Newton's second law. When one understands absoluteness with respect to rotation, space is absolute in Newton's mechanics and in Einstein's relativity as well. One may identify the aether with absolute space, or one may see in the aether an object in space, an object with no place, no time, no orientation, but serving as reference for velocities. But there is no impact on dynamics at all. Objects with these properties are the cosmic background of the different neutrinos, WIMPS, photons. With respect to the photon background, the Earth moves with about 500 km/s. Therefore, a Michelson-type expectation would be prominent in the Michelson experiment.

The thirteen lectures delivered at the Michelson Colloquium (Treder, 1982), with large thematic variety gathering round the Michelson experiment as the focus, especially appreciated its importance for physics and astronomy and dealt with philosophical and scientific historical aspects of the Michelson experiment. They took place during two days in a solemnly decorated room of the old city-hall of Babelsberg.

3. Friedrich Wilhelm University Berlin 1881

On April 28, Hans-Juergen Treder (1928-2006) (Astrophysical Observatory Potsdam, Potsdam, Germany) opened the jubilee colloquium and Michelson exhibition by welcoming special guests and participants to the internationally organized colloquium which was understood as a natural follow-up to the Einstein Centenary celebrations (**Figure 3** and **Figure 5**) held in Berlin and Potsdam in 1979.

J. Auth (1930-2011; Humboldt University, Berlin, Germany) delivered the opening lecture "Albert A. Michelson at the University of Berlin". By means of documents from the archive of the Humboldt University, Auth portrayed Michelson's scientific visit to Berlin and the preparation of the experiment. In that he built upon a detailed investigation of H.J. Haubold and R.W. John "Albert A. Michelson's aether drift experiment 1880/1881 in Berlin and Potsdam" (Treder, 1982; Haubold & John, 1981, 1982). Auth also sketched the social life of that time at the University of Berlin. In detail he devoted his attention to the theory and the physical consequences of the Michelson experiment.

4. Dorothy Michelson Livingston: Biograph of Albert A. Michelson

Dorothy Michelson Livingston (1906-1994; New York, USA) delivered the keynote address titled "Michelson and Einstein, artists in science". Mrs. Michelson Livingston (**Figures 7-11**) drew a vivid picture of her famous father and analysed the characteristics of his creative activity, especially in comparison with Albert Einstein. From her memories she made the audience familiar with the great experimental physicist Albert A. Michelson, who was painting with pleasure in his spare time and was athletically active up to the old age. At that the lecturer showed slides from her private photo collection. Mrs. Michelson Livingston is the author of the outstanding Michelson biography "The Master of Light", first published in 1973 (Treder, 1982; Michelson Livingston, 1973; Ryan, 1987; Millikan, 1938; The Albert A. Michelson Nobel Prize and Lecture, 1966). She finished her lecture with words spoken by Einstein in appreciating Michelson when meeting him at the California Institute of Technology, Pasadena, in January 1931, a few months before the death of Michelson: "It was you who led the physicists into new paths, and through your marvellous experimental work paved the way for the development of the theory of relativity" (see also **Appendix**).

4.1. Topic Einstein and Michelson (Hoffmann & Dukas, 1973; Haubold & Yasui, 1986)

"I always think of Michelson as the artist in science. His greatest joy seemed to come from the beauty of the experiment itself, and the elegance of the method employed. But he has also shown an extraordinary understanding for the baffling fundamental questions of physics. This is evident from the keen interest he has shown from the beginning for the problem of the dependence of light on motion."

—Albert Einstein (Livingston, Dorothy Michelson. The Master of Light: A Biography of Albert A. Michelson (Michelson Livingston, 1973)

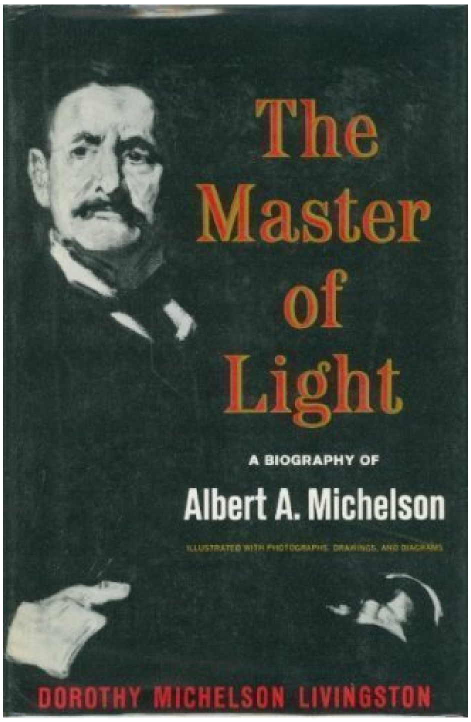


Figure 7. Cover of the original edition of the Michelson biography published in 1973 by Dorothy Michelson Livingston. This biography describes in detail Michelson's scientific work against the background of family life. Her book, which she has described as "a quest for my father", is the result the life-long research that let her travel through the world, particularly through all of European countries where her father pursued scientific studies.
https://digital.case.edu/islandora/object/ksl:2006061209

Figure 8. Dorothy Michelson Livingston opening speech of the Michelson Colloquium.

Princeton N.J.08540.May 24,1971
112 Mercer Str.

Mrs.Dorothy Michelson Livingston
209 East 72nd Str.
New York N.Y.10021

Dear Mrs. Livingston:

I received your letter of the 21.of May today and I would sincerely wish to be able to help you. Unfortunately, I shall not be able to. Professor Holton in his "ISIS" article quoted Professor Einstein from a letter to F.G.Davenport,Monmouth College in which he stated "I even do not remember if I knew of it[the Michelson result] when I wrote my first paper on the subject[relativity] in 1905". And in a letter to Mr.B.Jaffe in March 1942 he wrote that "I was pretty much convinced of the validity of the principle[of the special theory of relativity] before I did know of this experiment and its results". Professor R.S. Shankland of the Case Institute in Cleveland,Ohio had conversations with Professor Einstein on the occasion of your father's 100.birthday. I suppose, however,that you are in touch with Professor Shankland.

The only mention of the Bern University Library I have found some time ago in a letter to his old friend Michele Besso,dated 1903,where he complains about having difficulties finding the material in the library for his work on molecular theory.

Although I do not know that whether the enclosed will be of any value to you I do send it to you. It is the report of the address Professor Einstein gave in the Physikalische Gesellschaft Berlin in memory of your father. I found it only recently.

Yours sincerely,
Helen Dukas
(Miss)Helen Dukas

encl.

Figure 9. Letter from Helen Dukas to Dorothy Michelson Livingston constituting the quest of her research on the relation between Einstein and Michelson and the role that Michelson's interferometer experiments played in Einstein's discovery of special relativity (Michelson Livingston, (1906-1994)a).

328 Bad Pyrmont / West Germany
Marcardstrasse 4.
June 5, 1964

Mrs. Dorothy Michelson Stevens,
209 East 72nd Street,
New York 21, N.Y.

Dear Mrs. Stevens,

I would be delighted to answer your questions about your father, but I am just too busy to do it properly. So I will say only a few words and hope to be able to send you a more detailed answer later.

Whether Michelson was 'bitterly disappointed' when his experiment gave a negative result, I can't say, but I am inclined to doubt it. He was a genuine, open minded scientist who did not start an experiment with definite expectations. He may have been surprised about what he found. He belonged to the generation which believed in the classical idea of matter, force, etc. But he would not have invited me, then a very young scholar, to come to Chicago and to lecture on relativity, if he had not been quite open minded to new ideas.

Nor do I think he was 'left behind' by the new theorists like myself, Lorentz and Einstein. He was just not a theorist, but a genius in the field of experiment. Perhaps he had a little poor idea of the value of theories. When I was in Chicago I studied under his direction arc-spectra emitted by different materials. There I noticed the many band spectra and was struck by the wonderful regularity of them. When I mentioned this enthusiastically to your father and said that there is a simple theory to explain them (proposed by Deslandres a.o.) he said: "Well, I show you that this can't be correct" and he directed my attention in the spectrum on a few striking irregularities in the distribution of lines. Then he added to my surprise: "I am pretty sure that no theory could ever explain such crazy behaviour." I was a little intimidated by this opinion. A few years later the theory was able to account for these anomalies (perturbations).

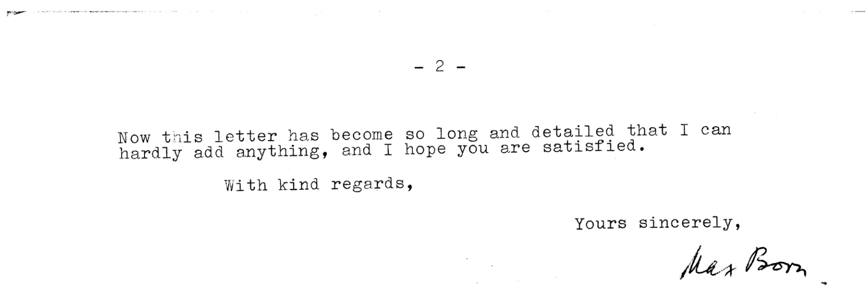
This shows your father's suspicion against the power of theories.

I don't know what his personal relations to Lorentz and Einstein were. He never uttered a critical word against them, at least in my presence. I don't know whether he knew them personally well.

I did not know Newcomb and Rowland, but I knew Lorentz quite well. He was a most attractive personality, very clear and sharp in his judgment and at the same time personally mild and kind. He and Einstein were in the prime of their lives, leaders in progress, but later became rather conservative. Lorentz never quite accepted relativity, as Einstein had established it. On the other hand Einstein never accepted quantum mechanics in its usual interpretation (suggested by myself).

I think this is the usual behaviour of old men and I am sure that my attitude to modern physics is just as conservative (though I am careful not to show this too frankly.)

Concerning your last question: my recollections will hardly be published during my life time.



- 2 -

Now this letter has become so long and detailed that I can hardly add anything, and I hope you are satisfied.

With kind regards,

Yours sincerely,

Max Born

Figure 10. Letter from Max Born to Dorothy Michelson Livingston summarizing Max Born's view of the Michelson experiment for the benefit of Einstein's research work in relativity (Michelson Livingston, (1906-1994)b).

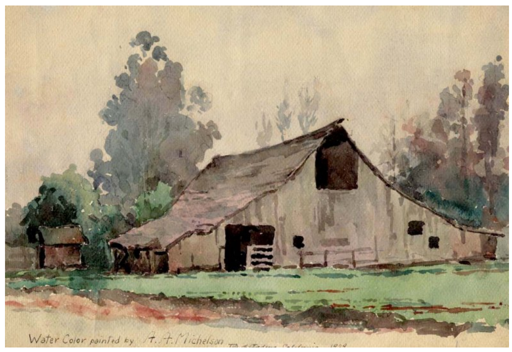


Figure 11. Watercolour painted by Albert A. Michelson, Altadena, California, 1929. Figure provided by the Special Collections & Archives Division, Nimitz Library, United States Naval Academy, www.usna.edu/LibExhibits/Michelson/Michelson_personal.html, Click on "Michelson Painting" for a video showing a Michelson painting accompanied b music composed by Michelson.

4.2. Topic Born and Michelson (Born, 2005)

The Michelson experiments were made by the American physicist Miller, first in flat country and later on top of Mount Wilson, a high mountain. To begin with, he claimed to have discovered, using his Michelson interferometer, the so-called aether wind. Sometime later he withdrew the claim; the shift of the interference fringes, on which he had based his claim, had been too small. I believe he then attributed it to the movement of the solar system. When I was in the United States in 1925/26, Miller's measurements were still frequently being discussed. I therefore went to Pasadena to see a demonstration of the apparatus on top of Mt. Wilson. Miller was a modest little man who very readily allowed me to operate the enormous interferometer. I found it very shaky and unreliable; a tiny movement of one's hand or a slight cough made the interference fringes so unstable that no readings were possible.

From then on I completely lost faith in Miller's results. I knew from my visit to Chicago in 1912 that Michelson's own apparatus was very reliable and his measurements accurate. My scepticism has been substantiated by later developments. Michelson's result that the aether wind does not in fact exist is universally accepted today."

4.3. ROOT-BERNSTEIN: Topic Artist Michelson

Albert Michelson had many interests outside of the realm of physics and science, including music, art, billiards, chess, and tennis. His interest in the violin began when he was a child, grew during his years at the Naval Academy, and eventually led to musical composition. Michelson expressed his interest in art through sketching and painting watercolors. The majority of Michelson's paintings were completed in his later years and during his retirement, consisting mostly of watercolors of California landscapes. Some of Michelson's watercolors were exhibited at the Pasadena Art Institute in 1931, shortly before his death (Root-Bernstein, 2006).

Michelson was also an artist. In 1928, he had a one-man exhibition at the Renaissance Society of the University of Chicago and exhibited two watercolours (Antofagasta, Chile and Vigo Harbor, Spain) at the Art Institute of Chicago's Eighth Annual Exhibition of Watercolours by American Artists. At one of these exhibits, "one woman told Michelson he should never have given up art for science. 'I did not have to choose,' he answered, 'because for me they are inseparable'". Indeed, 25 years previously, in his book Light Waves and Their Uses (1903), Michelson had written:

And painting lessons each Sunday from Rudolph Weisenborn at the Chicago Academy of Fine Arts and amused himself by drawing caricatures of acquaintances. After he remarried, he built a house in Chicago in 1923 with a conservatory in which his wife grew flowers and both sat and drew or painted, a habit they took outdoors in their later years in Pasadena, California.

As a supplement communication during the Michelson Colloquium, Mrs. ***Dorothy Michelson Livingston*** made a lively presentation with photography and paintings on her father as an artist in science and technology.

5. Case Western Reserve University 1887: Michelson-Morley Experiment

R. S. Shankland (1908-1982) (Case Western Reserve University, Cleveland, Ohio, USA) on "Michelson in Potsdam" did summarize the results of the experiments in Potsdam and in Cleveland in 1887, when Michelson in cooperation with E.W. Morley repeated the aether-drift experiment with higher precision. The result confirmed the null result of the Potsdam experiment. Shankland himself was leading engaged in the disclosure of the misinterpretation of the result announced by D.C. Miller in single carrying out a further repetition of the Michelson experiment. Shankland lucidly and concisely presented that part of Michelson's scientific activity, which begins with his collaboration with S. Newcomb, then, in 1880, lead to the visit to Europe—stations were Paris and Berlin/Potsdam—and which included the invention of the Michelson interferometer, its construction in Berlin, the preparation of the experiment in Hermann von Helmholtz' institute, and finally, the realization of the experiment in the Astrophysical Observatory Potsdam. At that time, H. von Helmholtz was already a famous scientist, inter alia for his contributions to physical optics and the foundation of physiological optics. His laboratory was a renown modern centre for optical research. This intensive scientific environment no doubt was an important factor in Michelson's progress, as Shankland stated (Treder, 1979; Shankland, 1953, 1954).

H. Melcher (1927-2022; Training College for Teachers, Erfurt, Germany) contributed a brief annotation concerning some special questions of the history of the aether-drift experiment and the genesis of special relativity (Treder, 1982; Renn et al., 2003).

R. Rompe (1905-1993; Physical Society, Berlin, Germany) and **G. Albrecht (1930-2015; German Academy of Sciences, Berlin, Germany)** focused in a joint presentation on a more general topic "The importance of experiments for the progress in physics". Rompe pointed out, how "the nearness of an experiment to experience", what was just existing yet in Michelson's investigations, today threatens to fade away due to the more and more increasing complexity of the experimental proceeding in physics and the necessary inclusion of electronic data processing. He stressed the tight nexus of physical conception, mathematical theory, and experiment. So, on one hand, the experimental advance is essential for the development of physical theory, but, on the other hand, according to a remark made by Einstein to Heisenberg, designing an experiment is again decisively co-determined by the theory. The lecturers spoke about the methodical benefit one may also yet today derive from Albert A. Michelson's, the great master of precision optics, style of working (Treder, 1982).

K. Lanius (1927-2010; Institute of High Energy Physics, Zeuthen, Germany) was dealing with the statistical evaluation of experiments in an additional part of the previous lecture (Treder, 1982).

H.-G. Schoepf (1928-2004; University for Science and Technology, Dresden, Germany) delivered on overview on the status of physics in the 19th century in his lecture "Maxwell's aether theories". In an enthusiastic and exciting manner, he coherently displayed the ways which have led Maxwell via different mechanical aether models to his famous equations of electromagnetism (Treder, 1982; Schöpf, 1978).

6. Michelson-Morley-Miller Experiments and Einstein's Relativity Theory

L. S. Swenson Jr. (1932-2016) (University of Houston, Texas, USA), the widely known historian of science, discussed in detail "The Michelson-Morley-Miller experiments and the Einsteinian synthesis". Swenson (**Figure 12**) described the history of these experiments in connection with the rise of the special theory of relativity (Treder, 1982; Swenson Jr., 1972). In that he stressed that the history of physics must be seen in connection with the history of technology. At the end of his lecture Swenson raised several questions concerning the history of the theory of relativity. He also highlighted that in the Munich Deutsches Museum letters from the Einstein-von Laue correspondence is deposited which should be published in the future.

Figure 12. From left U. Ulmer (youngest daughter of D. Michelson Livingston), D. Michelson Livingston, R.W. John (1942-2007; co-organizer of the Michelson Colloquium), L.S. Swenson, during the deliberations of the Michelson colloquium in Potsdam 1981. https://researchfeatures.com/dorothy-michelson-livingston-personal-recollection/

SWENSON: Research Topic Michelson Experiment

In summary here, let me suggest a series of five primary problems and unanswered questions which seem to me to be middle range historical needs for further research (Treder, 1982):

1) Has anyone done a comparative experimental biography of the pioneer terrestrial measurers of the velocity of light, focussing on the French school, especially Foucault and Fizeau in I850? This seems a big and dramatic problem.

2) Do we have adequate monographic accounts of the works of Michelson's mentors, particularly of Jamin,

Mascart, Cornu, Quincke, and Vogel? What is the best historical work on Hertz?

3) Has Walter Ritz's attempted revival of the emission theory of light around 1907 been adequately studied? Have the specific contributions and influence of Georg Joos at Jena with Zeiss interferometers of 1930 been re-examined?

4) Since the work of Shankland and his group in I955, has any astrophysicist or celestial mechanician re-examined the significance of Dayton Miller's "secret history" and review paper of 1935 "The Ether-Drift Experiment and the Determination of the Absolute Motion of the Earth", Reviews of Modern Physics 5: 203-234, July 1933? Gustav Stroemberg at Mount Wilson before his death suggested some oversights here.

5) Is there any adequate treatment of Max von Laue and his relations with

Einstein? There are 44 letters in the Münchener Deutsches Museum that should be suitably published, von Laue was one of Einstein's first and last friends, a peer!

7. Aether Models

J.P. Vigier's (1920-2004; Institute Henri Poincare, Paris, France) lecture opened the modern view of "Einstein's and Dirac's aether models". After having stated the classical aether models are killed by the null result of the Michelson experiment, Vigier (**Figure 13**) investigated the justification of stochastic covariant aether models. He dealt with the relativistic generalization of results obtained by Einstein and Marian von Smoluchovsky on Brownian motion. Discussing the relation of superluminal velocities and causality he rested upon experiments performed by A. Aspect (Treder, 1982; Vigier, 1997).

Figure 13. From the left V. Vigier, Z. Maric, and E. Kreisel (b. 1937). In the background examples are visible of the 12 large exhibition panels (**Figure 2** and **Figure 4**) produced for the Einstein Centenary 1979 in Potsdam and Berlin and the Michelson Colloquium 1981 in Potsdam.

8. Quantum Mechanical Measuring

F.W. Kaschluhn's (1927-1994; Institute of Theoretical Physics, Humboldt University, Berlin, Germany) "Interference and correlation phenomena in quantum theory" perspicuously worked out a problem connected with the microphysical description of single systems, the overcoming of which obviously demands additional assumptions about the quantum mechanical measuring process (Treder, 1982).

Z. Maric (1931-2006; Institute of Physics, Belgrade, Yugoslavia) posed his lecture, likewise dealing with quantum field theory, under the theme: "Vacua and symmetries". Maric (**Figure 13**) investigated the vacuum concept on different stages of development of physics, especially he emphasized the relation of this concept to the internal geometry of space (Treder, 1982).

J. Stachel (b.1928; Department of Physics, Princeton University, Princeton, USA) focused in his lecture titled "Einstein and Michelson: The Context of discovery and the context of justification" on the fact that a philosopher of science is not interested in the context of discovery, but in the context of justification and that it appears amazing to what extent the logical analysis of relativity coincides with the original interpretation by its author, as far as it can be constructed from the scanty remarks in Einstein's publications. According to Stachel (**Figure 14**), in contradistinction to some developments in quantum theory, the logical schema of the theory of relativity corresponds surprisingly with the program which controlled its discovery. This agrees with the independent analysis of philosophers and scientists as Hans Reichenbach and Gerald Holton (Treder, 1982; Stachel, 2002; Holton, 1988).

Figure 14. H.-J. Treder and J. Stachel in front of the fireplace in Einstein's Summer House in Caputh.

H.-J. Treder (1928-2006) (Observatory Babelsberg, Potsdam, Germany) celebrated in the concluding speech of the colloquium "The Michelson experiment as experimentum crucis". Dealing with this theme, and simultaneously aspiring a synopsis of the most important statements involved in the foregoing lectures, Treder (**Figure 14**) stressed the following central aspects: The art and importance to perform experiments, the creation of new experiments from putting of important physical questions; the question of the existence or non-existence of the aether; the meaning of classical questionings, from Michelson to Einstein and from Einstein to Bohr, at the present time (Treder, 1982).

TREDER: Topic History Michelson Experiment Potsdam

There are several problems and unanswered questions which seem to me to be middle range historical needs for further research:

The Einstein effect that needs a better historical comprehension of the expedition of Freundlich.

Schwarzschild was an important representative relativity theory: Why did Einstein focus on Freundlich and not focus on Schwarzschild in the case of experimental verification of the curvature of space.

In the period of time from 1922 to 1932 there existed a curatorium for the Astrophysical Observatory Potsdam (von Laue, Einstein, Nernst, Mueller, Gehrke, Paschen, Schrödinger). What did this curatorium pursue? (Treder, 1928-2006).

The organizers of the Michelson Colloquium took advantage of this event in planning visiting opportunities between lecture sessions and beyond. All participants of the colloquium were invited to visit the main building of the Astrophysical Observatory Potsdam (**Figure 1**), the Einstein Tower on the Telegrafenberg (**Figure 15**), and the Einstein House in Caputh near Potsdam (**Figure 16**). Many of the colloquium lectures did touch historical, scientific, and social issues which are part of research programmes as analysed in depth, for example, in Holton's scientific papers. Long time after the discoveries addressed by lectures of the Michelson Colloquium the decision was made to rename the main building of the Astrophysical Observatory to be the Michelson building to honour Michelson's first experiment.

Figure 15. Einstein Tower, Telegrafenberg, Potsdam.

Several participants had the unique opportunity to be accommodated as guests in the summer house of Einstein in Caputh and were invited to continue the colloquium deliberations in guided tours and discussion sessions (**Figure 16** and **Figure 17**). The summer house built for Albert Einstein in Caputh close to Potsdam in 1929 by the young architect Konrad Wachsmann is of great cultural and architectural importance. The house is the result of close interaction between the requests of Albert Einstein and the ideas of Konrad Wachsmann. The ample window front of the spacy living room with its open lightness goes back to the ideas of the architect and invited even at Einstein's time to meeting sessions. Unfortunately, constant change of use and ownership as well as lack of financial resources and material resulted in a lack of maintenance work. Over long time, legal debate about the ownership of the house prevented necessary restoration. Yet through all ups and downs of its history the house has preserved a high degree of authenticity and has always remained the "summer house of Albert Einstein". During the Michelson Colloquium the house was elevated to be the host of the Einstein Laboratory for Theoretical Physics lead by H.-J. Treder.

Figure 16. Einstein's Summer House in Caputh.

Figure 17. From the left U. Ulmer, F.W. Jaeger (1914-2000; former director of the Einstein Tower, Telegrafenberg, Potsdam), D. Michelson Livingston in the Einstein House Caputh, in the background the Einstein bust created by Heinrich Drake in 1981.

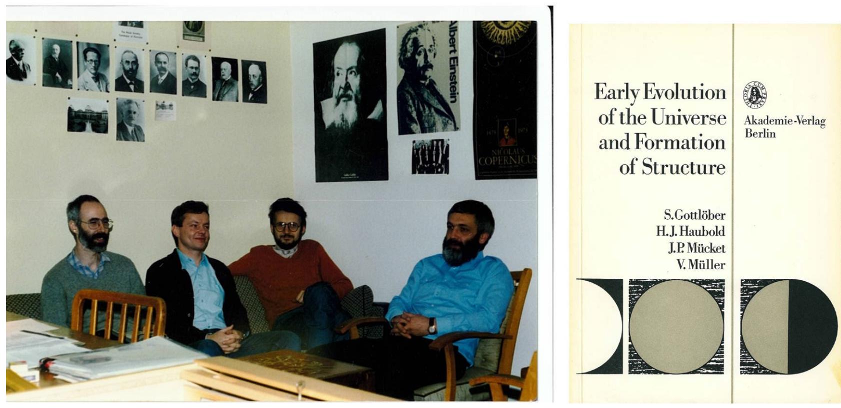
A unique element of the programme of the Michelson Colloquium for all participants was the opportunity to visit the Einstein Tower through guided tours and discussion sessions. The Einstein Tower is an astrophysical observatory on the Telegrafenberg later to become the Albert Einstein Science Park in Potsdam, Germany, built by architect Erich Mendelsohn. It was built on the summit of the Potsdam Telegrafenberg to house a solar telescope designed by the astronomer Erwin Finlay-Freundlich. The telescope supports experiments and observations to validate (or disprove) Albert Einstein's relativity theory. The building was first conceived around 1917, built from 1919 to 1921, and became operational in 1924. Although Einstein never worked there, he supported the construction and operation of the telescope. Light from the telescope is directed down through the shaft to the basement where the instruments and laboratory are located. In 1911 Einstein published the initial version of his General Theory of Relativity. One of the predicted effects according to the theory was a slight shift of spectral lines in the sun's gravitation field, now known as the red shift. The solar observatory in Potsdam was designed and constructed primarily to verify this phenomenon.

100 years were gone since the Michelson experiment was performed for the first time in Potsdam—this also meant 50 years since Albert A. Michelson's death—but, as the lectures of the Michelson Colloquium showed, the physical and scientific historical discussion continuously inflames at this decisive experiment which signalized a revolution in the development of physics. Also, in dealing with questions in more distant fields, the discussions looked back at this experiment as a pioneering event in the history of physics (Bussemer & Mueller, 2022; van Dongen, 2009).

Acknowledgements

Professor Dr. Johann Wempe (1906-1980), former director of the Astrophysical Observatory Potsdam. He was the editor of the Astronomische Nachrichten journal for 22 years and, after his retirement, became interested in the history of astronomy in Potsdam. In 1975 it was him who announced publicly that Alber A. Michelson performed his famous experiment in the AOP in 1881. Dring the visit of Dorothy Michelson Livingston on her trip through Europe for the benefit of her writing the biography of father, Wempe joint her in Berlin and Potsdam to explore what today is known about the Michelson cellar at the AOP (personal communication in 1975).

Members of the Working Group on Formation of Structure in the Universe (Jan-Peter Muecket, HJH, Volker Mueller, and Stefan Gottloeber), contributing to the Michelson Exhibition 1979 and 1981 at the Astrophysical Observatory Potsdam and Astronomical Observatory Babelsberg.



All lectures given, and discussions pursued during the Michelson Colloquium have been recorded and are made available on request (courtesy of Klaus Fritze, Observatory Babelsberg, Potsdam, Germany).

Text and photos of all 12 panels (in German language) of the Michelson exhibition for 1979 Einstein Centenary and 1981 Michelson Colloquium are available on request (courtesy of Horst Strohbusch, Astrophysical Observatory Potsdam, Telegrafenberg, Potsdam, Germany).

The author undoubtedly failed to include publications by other authors that have equally good connections with, or illuminating commentary on, the issues told in this article. The author shall be grateful to those who write to him to point out such deficiencies.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Michelson Livingston, D. ((1906-1994)a). courtesy of, youngest daughter of Albert A. Michelson, Letter from Helen Dukas, former life-long secretary of Albert Einstein to Dorothy Michelson Livingston dated 24 May 1971, Fig 9. personal communication with HJH in Wainscott (July 1989).

Michelson Livingston, D. ((1906-1994)b). courtesy of, youngest daughter of Albert A. Michelson, Letter from Max Born, close friend of Albert Einstein, to Dorothy Michelson Livingston, dated 5 June 1964, Fig 10. personal communication with HJH in Wainscott (July 1989).

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Wempe, J. (1906-1980). former Director of the Astrophysical Observatory Potsdam, personal communication with HJH (1 March 1979), discovering that the first trial of Michelson with his interferometer, build by Schmidt + Haensch Berlin, was not set up in the Magnus-Haus in Berlin, but in the Physical Laboratory of Hermann von Helmholtz.

Appendix

Keynote Address of Dorothy Michelson Livingston Prepared for the Einstein Centenary Berlin 1979 and the Michelson Colloquium Potsdam 1981.

private Mitteilung 01.10.1979 H.J.H.

EINSTEIN AND MICHELSON

Artists in Physics
By
Dorothy Michelson Livingston

Between a theorist and an experimentalist there lies a fundamental difference. The man who works with his brain alone has a limitless field, while the other is bound to his instruments. But between them there is also a bond. They complement each other. Theories lead only so far, and then there must be some sort of definite proof which can only be found by experiment. Einstein and Michelson are excellent examples.

One hundred years ago, the year of Einstein's birth, Michelson, at twenty-seven, measured the speed of light and was honored for this feat by an invitation to address the American Association for the Advancement of Science. The NEW YORK TIMES reported: "It would seem that the scientific world of America is destined to be adorned with a new and brilliant name. Ensign A. A. Michelson, a graduate of the Annapolis Naval Academy ... "

The velocity of light, known as "C," which Michelson later refined, would figure in Einstein's equation $E=MC^2$. And thus their somewhat involuntary association began.

Michelson had graduated from the Naval Academy in 1873, had been to sea for two years, and had become an instructor in physics when he was told to demonstrate for his pupils Foucault's method for measuring the speed of light. Finding certain inadequacies in the Frenchman's method, he made some adjustments and came up with a figure 200 times more accurate.

His next experiment played even more closely into Einstein's hands. Inspired by a letter from James Clerk Maxwell to Todd of the Nautical Almanac, Michelson conjured up a method by which he hoped to measure the speed of the earth through the ether, a medium believed to fill all space.

He left Washington in 1880 to study with the German physicist, Hermann von Helmholtz, with whom he discussed the problem. It was to be accomplished by means of a remarkably simple device made up of three mirrors and a lens. Alexander Graham Bell paid for these mirrors, which Michelson assembled in a manner to flash a beam of light moving against the earth's motion and one across this motion. As a ship drags a log in the water to determine its speed, so Michelson hoped to record the earth's speed through the ether.

He set up his instrument first in Berlin in the basement of the University. Disturbed by traffic vibrations, he moved it to Potsdam under the main tower of the astrophysical observatory. Everything worked to perfection. Only, to his bitter disappointment, the outcome was negative. That is, the two beams of light projected in different directions came together simultaneously, whereas he had hoped that the beam moving against the earth's motion in orbit would lose the race.

News of this negative result spread rapidly and the physicists were sorely puzzled. All of them believed implicitly in the ether theory because this medium was thought to carry light waves. So Michelson was encouraged to repeat his experiment with the aid of a chemist named Morley in Cleveland. The Michelson-Morley experiment, performed in 1887 with far superior equipment, resulted in the same frustrating negation.

All kinds of reasons were dreamed up to explain it, the most plausible of which was the FitzGerald-Lorentz "contraction theory." This theory explained the negative result by assuming that a moving object was shortened in length by an amount corresponding to its speed in motion. So that Michelson's interferometer, as his assembled mirrors were called, moving with the earth's speed in orbit, would be compacted just enough to defeat the measurement.

H. A. Lorentz wrote a lengthy paper on this theory, published in 1895, in which he described the Michelson-Morley experiment in detail. Einstein was sixteen at the time, already manifesting his absorbing interest in physics and mathematics. He had studied Maxwell's electromagnetic theory and asked himself the riddle: what would a light wave look like to someone riding with it?

Between 1895 and 1905 when he published the special theory of relativity, he had occasion to reflect on the ether theory and its many flaws. Defined as an impalpable, imponderable fluid occupying all space, a tenuous jelly or an "elastic fluid," it could supposedly penetrate steel or permeate a vacuum. Yet the planets rolled through it undeterred, without friction or loss of speed. But the angle that stimulated his thinking more than any other was the proof by the ether drift experiments that light moves at exactly the same speed whether it is approaching or receding from the observer.

With this information, which had long been suspected, Einstein quietly declared the ether irrelevant. How simple! No further problem. Light still moved in waves as well as in quanta, and the universe expanded "relatively."

Einstein looked for recognition from four men in particular after publication of the special theory: Ernst Mach, his mentor; H. A. Lorentz with whom he had corresponded; Henry Poicarré, who coined the word "relativity;" and Michelson. But to his disappointment none of them came forth with definite approval. The physicists were sharply divided in their opinions. Even as late as 1921 when Einstein won the Nobel prize, no mention was made of relativity.

When Einstein and Michelson met at various scientific gatherings during the twenties, it was without enthusiasm. Einstein was never one to harbor a grudge, but his star was rising while Michelson found himself no longer at the center of discussion. He had never liked the new theory, and he preferred the wave theory of light to thinking of it as a corpuscle. And waves need a medium, call it what you like--space, perhaps.

In 1911 Michelson spent a winter in Göttingen, then the Mecca for physicists, delivering a series of lectures. Einstein had been there in 1910, and the younger men were full of talk about his revolutionary ideas. They gathered after class in one of the popular bierstube dividing themselves between two tables, one pro relativity and the other anti the new theory. As Michelson appeared after one of his lectures, everyone watched as he hesitated between the two and then took his seat decisively among the conservatives.

Eventually he was forced to accept the new concept. But it was not without a certain nostalgia for what he referred to in 1929 as "my beloved ether."

There is something, of course, about a theoretical mathematician which seems almost magical to the layman. A story about Einstein, probably apocryphal, has him and his wife up on Mt. Palomar examining the new two-hundred inch telescope. Proudly their guide demonstrates how this marvelous instrument, costing many millions, by scanning the heavens could reveal the secret of the universe.

"Too bad you spent all that money," said Mrs. Einstein, "Albert just needed his pencil!"

The experimentalist must know what theory to prove, as he is dependent on the vital line of investigation. Michelson chose the ether theory. It was just his hard luck that his own brain child, the interferometer, plus his accurate measurement of C caused the downfall of the physical concept in which he had been reared. On receiving the congratulations of a French physicist, Michelson replied, "Je n'ai pas voulu cela."

Where these two men differed most was in politics. Einstein had a world view of civilization as a whole, whereas Michelson, with his navy background, was passionately nationalistic. Loyalty to his country, particularly under attack, took precedence even over his investigations on the behavior of light. At the barest threat of danger he re-enlisted.

He spent the Spanish American War patrolling Lake Michigan training cadets. In 1917 he was back in uniform in Washington, applying his knowledge and experience in grinding lenses to the perfecting of optical glass. Einstein, on the contrary, was somewhat removed from the everyday world. My parents found him rather naive on lay matters. During prohibition he argued for restoring the saloon, equating it with the German bierstube, where intellectuals gather to exchange ideas. He became an easy mark for groups that wanted an endorsement.

Americans have a way of idolizing a man who has proven himself along one line of endeavor by making him out a genius in every walk of life. After Lindberg flew the Atlantic, they tried to make him President. When a genius like Einstein is solving the riddle of space-time curvature, why should we bother him with our local problems?

While Michelson was repeating his measurement on the speed of light on Mt. Wilson in Pasadena, California, he received an invitation to a dinner given in honor of Dr. Einstein by the California Institute of Technology. Speaking in German, Einstein generously acknowledged Michelson's contribution in these (translated) words:

"You, my honored Dr. Michelson, began with this work when I was only a little youngster hardly three feet high. It was you who led the physicists into new paths, through your marvelous experimental work, paved the way for the development of the theory of relativity. You uncovered an insidious defect in the ether theory of light, as it then existed, and stimulated the ideas of H. A. Lorentz and FitzGerald out of which the special theory developed. These in turn pointed the way to the general theory of relativity and to the theory of gravitation."

In spite of their differences, these two men had much in common. As their friendship grew during Michelson's later years in Pasadena, they found they shared many tastes. Both of them enjoyed sailing small boats and both of them played the violin with considerable skill. They agreed that Mozart was their favorite composer. Einstein took his violin with him wherever he went. Michelson found relaxation painting landscapes in watercolor. On his frequent travels, he always carried his paint box. Science came first of course. Human relations were less important. It was necessary for both men to spend most of their time alone.

The strongest bond existed in their belief in the importance of an aesthetic approach to their scientific problems. Addressing his audience at the Lowell Institute in 1899, Michelson said: "If a poet could at the same time be a physicist, he might convey to others the satisfaction, almost the reverence which the subject inspires. The aesthetic side of the subject is, I confess, by no means the least attractive to me. Especially is its fascination felt in the branch which deals with light."

Many years later after Michelson's death, Einstein paid him this tribute: "I always think of Michelson as the artist in science. His greatest joy seemed to come from the experiment itself and the elegance of the method employed...."