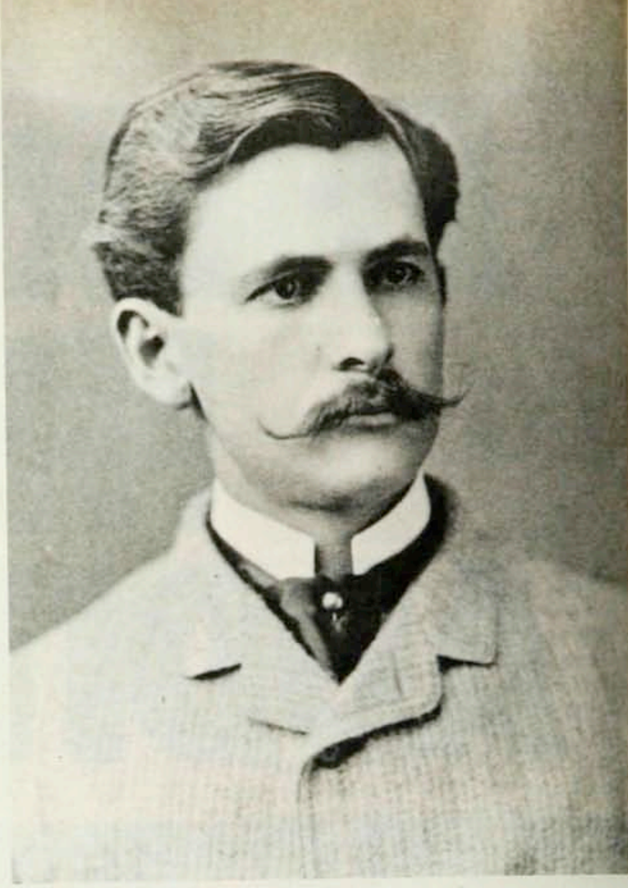
Michelson in 1887

The year of the famous ether drift experiment and the use of light waves as a standard of length was also a year for personal problems, including a damaging scandal.

Albert E. Moyer



Albert Abraham Michelson in 1887. (Photograph courtesy of Clark University Archives.)

In July 1907, Bernhard Hasselberg, a member of the Nobel Prize committee, confided to George Ellery Hale that Albert Michelson was his choice for the year's physics award: "In *my* opinion he is in every way, and absolutely without comparison, the most meritorious of all the gentlemen now proposed to us."[1] After the Swedish committee chose Michelson, making him the first American ever picked for a Nobel science prize, Hasselberg was even more complimentary. He wrote to Hale that Michelson's selection "is the *best* of all which have been made up to this date. Our earlier laureates Röntgen, Lorentz, Zeeman, Becquerel, Curie, Rayleigh, Lenard and J. J. Thomson are indeed men of eminent scientific merits, but for my part I consider the work of Michelson as more fundamental and also by far more delicate." Even if we allow for the idiosyncrasies of the Nobel selection process and for Hasselberg's personal biases, we still must grant that by 1907 Michelson had earned the respect of the international physics community.

Exactly 20 years earlier, in 1887, Michelson had begun the investigation with Edward Morley that eventually provided one of the main justifications for his Nobel Prize. What was this work? It was not the "Michelson–Morley experiment," the famous interferometer test for Earth's drift through the supposed ether. Rather, it was another collaboration with Morley using the same interferometer—an investigation to determine whether wavelengths of light could provide a standard unit of length. Whereas the Nobel committee stressed the importance of the latter research along with other precision measurements, it failed even to mention the ether drift test. This omission does not mean that scientists in 1907 were unaware of the test. During the prior two decades, Hendrik Lorentz, George Fitzgerald, Henri Poincaré and Joseph Larmor had been grappling with its confusing result. Even the royalty of British physical science, Lords Kelvin and Rayleigh, had been keeping tabs on "Michelson's celebrated experiment" and its "well-known negative result."[2] Awareness of an experiment, however, differs from appreciation. Widespread appreciation of the test's significance would come only after Michelson's Nobel Prize, when the physics community grasped the full implications of Albert Einstein's special theory of relativity.

In this article, I return to the crucial year of 1887—the year in which Michelson, assisted by Morley, undertook the two research projects that independently contributed to Michelson's Nobel Prize and to his post-Einsteinian fame. Although I discuss both the standard-of-length and the ether drift project, I do not analyze them in detail; such studies already exist.[3] Rather, I aim to show how Michelson, in his 1887 investigations, fit into the larger picture of the day's physics, including both conceptual and institutional aspects, especially in the United States. Because Michelson's personal circumstances influenced his professional affairs, I also provide a glimpse of his private life.

Joining a network of physicists

Physicists in the United States in 1887 felt cut off from the scientific capitals of Europe—Berlin, Paris and London. Michelson felt especially isolated. A professor since 1882 at the fledgling Case School of Applied Science in Cleveland, he felt separated from even his American colleagues,

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Edward W. Morley around 1885. (Photograph courtesy of Case Western Reserve University Archives.)

such as Henry Rowland at the decade-old Johns Hopkins University, John Trowbridge at Harvard's new Jefferson Physical Laboratory and Willard Gibbs at Yale. In a letter to Rowland, Michelson complained of "the inconvenience of being so far removed from scientific centers," and added that "I would much prefer a position farther East."[4] Other scientists shared this perception of Cleveland's isolation. When the American Association for the Advancement of Science met there in the summer of 1888, the permanent secretary excused the disappointingly low attendance by pointing to the "natural aversion to going into the interior of the country in August."[5]

The founders of Case had sought to bring science and its practical applications to the Midwestern industrial city. But the five-year-old program suffered a setback in the fall of 1886 when a fire destroyed the main academic building, including much of the physics apparatus that Michelson had painstakingly assembled. As Michelson began the year 1887, damaged facilities compounded the problem of isolation.

However, Michelson, unlike many of his less enterprising colleagues throughout the United States, found ways to compensate. In response to the immediate problems caused by the fire, he relocated his laboratory and salvable apparatus to a building of nearby Western Reserve University, the home institution of chemist Morley, Michelson's research partner since 1885. As for the more basic problem of isolation, Michelson followed the lead of other active researchers by participating in an informal informational network. The network, which the scientists sustained through letters and travel, was both national and international in scope.

Michelson had become well connected within the domestic branch of the network. At the beginning of his career, while investigating the speed of light as a student and instructor at the US Naval Academy, he had formed a close professional bond with Simon Newcomb. Newcomb, the influential head of the government's Nautical Almanac Office, opened many doors for Michelson at home and abroad. Michelson also established close ties with two of the nation's most esteemed academic physicists, Rowland and Gibbs. For example, around 1884, when Michelson began to plan for a definitive ether drift experiment—a refined version of the experiment he originally performed in Germany in 1881—he consulted with Gibbs. Through conversation and correspondence, he questioned the Yale theorist about "the feasibility of the experiment."[6] Other members of Michelson's American network included physicists George Barker and Alfred Mayer, both of whom in earlier years had tried to get Michelson a job outside the Navy. Barker, of the University of Pennsylvania, finally arranged for Michelson's appointment as a professor through an influential friend at Case. "I am sure," Barker wrote to his friend, "the Case School will never regret this step."[7]

Michelson also cultivated relationships with prominent Europeans, the anchors of the physics network. These ties dated back to his days as a postgraduate student in Germany and France. Like other Americans faced with the shortcomings of American graduate schools, Michelson was particularly attracted to the University of Berlin, the site of Hermann von Helmholtz's famous laboratory. Beginning in the fall of 1880, Michelson attended Helmholtz's lectures on theoretical physics. In addition, he turned to Helmholtz for advice on his first ether drift test and his newly devised interferometer. While in Germany, Michelson also studied optics and spectroscopy under the masters in these fields. In the fall of 1881, he went on to Paris, expanding his list of scientific contacts to include the leaders in French optics. (See the article by Loyd Swenson on page 24.)

Although he visited London too, Michelson became close to top British physicists only after returning to the United States. In 1884 Michelson attended the Montreal meeting of the British Association for the Advancement of Science, chaired by Rayleigh, and heard the subsequent "Baltimore lectures," delivered at Johns Hopkins by William Thomson (later Lord Kelvin). Rayleigh and Thomson quickly became two of the most consequential members of Michelson's network, providing him with perspective and encouragement on his research. While in North America, they advised him to repeat his German interferometer experiment, but only after first checking

Armand Fizeau's earlier result on the speed of light in moving water. Michelson accepted this advice, reporting to Thomson in March 1886 that he and Morley had confirmed Fizeau's result.[8] A letter from Rayleigh then provided the incentive for Michelson and Morley to push on to the next stage of their ether research, a repeat of the interferometer test. Michelson wrote back to Rayleigh in March 1887 that he had been distressed by the lack of interest of his "scientific friends" and the "slight attention" the German test received. He continued, "Your letter has however once more fired my enthusiasm and it has decided me to begin the work at once."

Experimenters and measurers

European physicists in the period around 1887 made a distinction that helps us understand the relation between Michelson's research and the physics of his day. The Europeans, particularly the Germans, distinguished between experiment and measurement.[9] Whereas "experimental physicists" typically investigated new phenomena related to unsettled theories, the "measuring physicists" typically devised precision instruments to refine the quantities specified in established theories or to update recognized physical constants. Michelson was primarily a measuring physicist, as evidenced by his attempts to make precise determinations of Earth's motion through the ether and of a standard of length using wavelengths of light.

Michelson fit in well with other Americans who favored using their laboratories for measurement.[10] Rowland, for example, showed this propensity in his measurements of the mechanical equivalent of heat and in his manufacture of diffraction gratings for use in his spectral studies. Most Americans, however, emphasized the experimental rather than the measuring side of laboratory practice. Well-known experimental work of the day included Mayer's study of the configurations of floating magnets, Trowbridge's electrical research on the "superficial energy" between alloys and Edwin Hall's systematic investigation of conductors, which led to the discovery of the "Hall effect." As in Europe, very few scientists specialized in theoretical physics or treated it as a distinct area of teaching and research. Gibbs proved to be the exception, with contributions to thermodynamics, statistical mechanics and the electromagnetic theory of light. The dearth of theorists reflected in part the lack of advanced mathematical training in the United States. Michelson himself once admitted to Mayer that he made "no pretense" of being a mathematician.[11]

To make their exacting measurements, Michelson and the other Americans needed precision instruments. For this they did not need to turn to their European colleagues for help. Rather, they drew on an indigenous tradition of first-rate engineering and manufacture. Two of the world's foremost fabricators of optical apparatus were in the United States, John Brashear in Pittsburgh and Alvan Clark in Cambridge, Massachusetts. Michelson and Morley relied on Brashear's shop for the delicate optical components required in their ether drift and standard-of-length investigations. And for all its disadvantages, living in Cleveland allowed them to gain an edge on fellow Americans because they had immediate access to the local firm of Warner and Swasey.[12] This precision manufacturing company, for which Morley served as a consultant, had won the contract to furnish all the mechanical and structural portions of the telescope for the Lick Observatory, the largest refracting telescope in the world. (See the article by Donald Osterbrock, PHYSICS TODAY, February 1979, page 40.) Shortly after Warner and Swasey completed the Lick project in October 1887, Michelson and Morley began working with them to devise a mechanically advanced instrument for the next phase of their standard-of-length investigation.

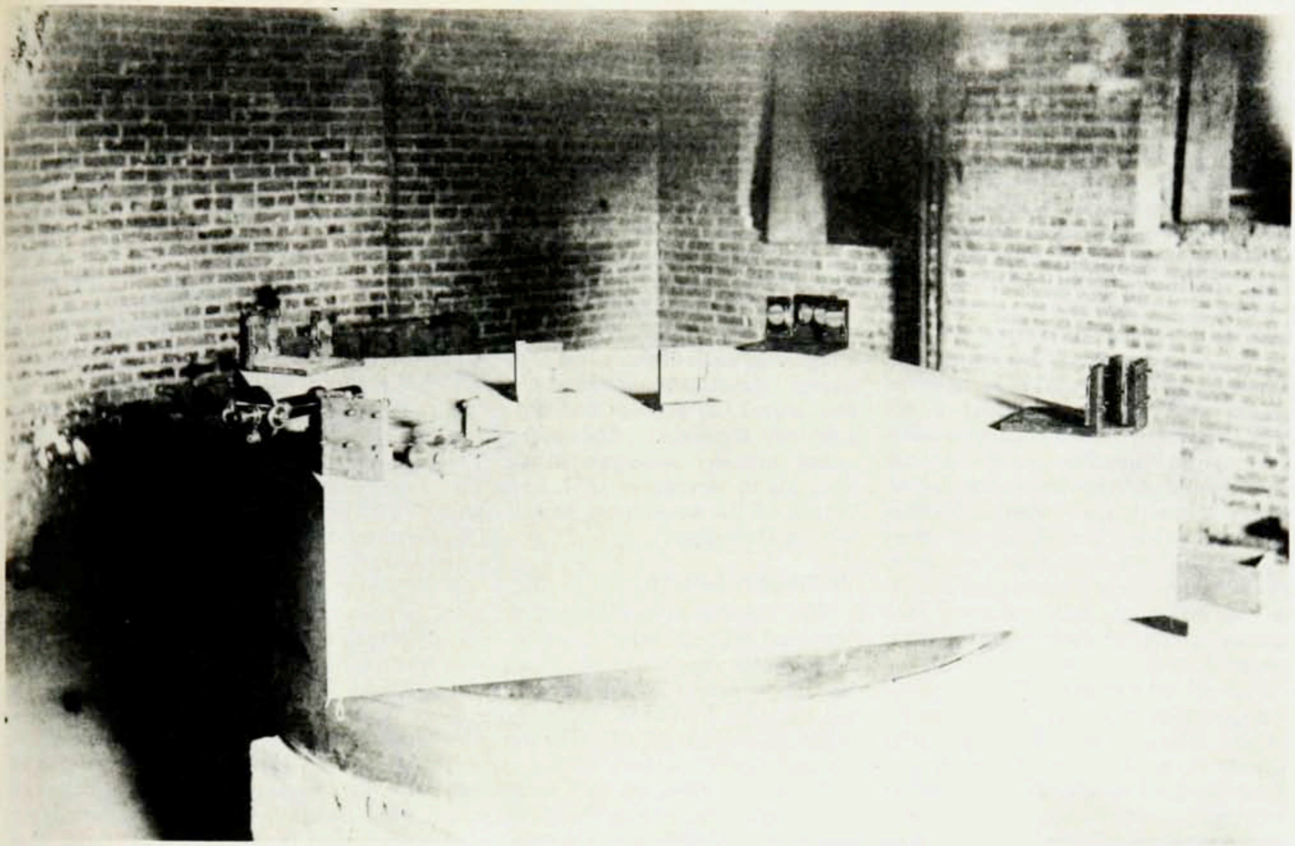
Conceptual framework

Whether they were experimenters or measurers, most American physicists around 1887 worked within the same general conceptual framework. Echoing many of their European colleagues, they assumed that all physical phenomena could be represented in terms of underlying atoms, molecules and ethers that obey the laws of classical mechanics. Although they shared the basic precepts of this traditional outlook as they pertained to gases, heat, electricity, magnetism, light and even gravity, the physicists were quite unsettled about specific mechanical theories and models. Michelson in particular coupled an orthodox trust in the existence of the luminiferous ether to an equally orthodox mechanical view of the atomic processes that caused light waves. Throughout an address to the 1888 Cleveland meeting of the AAAS, he confidently spoke of "the forces and motions of vibrating atoms and of the ether which transmits these vibrations in the form of light."[13] Although convinced of the existence of the ether, Michelson was unsure of Augustin Fresnel's specific hypothesis that the ether was essentially at rest relative to the moving Earth. Thus, he set out with Morley to make a definitive measurement of the relative Earth–ether motion.

The measurement's well-known null result threatened Fresnel's overall theory of the ether but not the notion of an ether itself. In fact, Michelson and Morley candidly reported their perverse result and then attempted to account for it with alternative explanations. First they considered the ether theories of George Stokes and Lorentz, concluding, however, that both of those options had their own weaknesses. Then they rationalized that the Earth's irregular surface perhaps had trapped portions of the ether, thus obscuring the "ether wind" they aimed to detect. Michelson and Morley never questioned the basic concept of the ether, just its particular character.

Michelson and Morley began working in earnest on the ether project soon after Rayleigh's encouraging letter. In April 1887, Morley reported to his father: "Michelson and I have begun a new experiment. It is to see if light travels with the same velocity in all directions. We have not got the apparatus done yet, and shall not be likely to get it done for a month or two."[14] Curiously, the measurement of ether drift was not to be the first application of their new interferometer—an ingenious arrangement of mirrors mounted on a sandstone megalith floating on mercury. They first employed the new device in June to explore the possibility of using the wavelength of one of the spectral lines emitted by thallium, lithium, hydrogen or especially sodium as a standard of length—as an unequivocal and invariant measure of a meter.

They initially addressed the standard-of-length question for a simple



Interferometer built by Michelson and Morley in 1887 for their famous ether drift experiment. (Michelson Collection, US Naval Academy.)

reason. While preparing the interferometer for the ether test, they first had to ensure that the perpendicular paths of the two light beams were of approximately equal lengths; they did this by adjusting the position of one of the plane mirrors at the end of one of the paths. They realized that if the mirror "moved parallel with itself a measured distance by means of the micrometer screw," then the distance could be correlated with an exact number of wavelengths; they could determine this number simply by counting alterations in the circular interference fringes as the mirror was moved.[15] Although Michelson had thought of the method "several years ago," they now confirmed that the method "seemed likely to furnish results much more accurate" than any prior determinations of length.

Not until July 1887 did Michelson and Morley finally set the adjusted interferometer into slow rotation and look for shifts in the interference fringes indicating the relative motion of the Earth and ether. A month later Michelson wrote to Rayleigh that the tests "have been completed and the result is decidedly negative."[16] In the ensuing months and years, Michelson came to value the ether drift test not for its null finding but for its role in the creation of a refined interferometer applicable to more pressing investigations, especially the determination of a standard of length. The Nobel Prize committee would agree.

Institutional resources

To announce their findings, Michelson and Morley traveled in early August to the meeting of the AAAS at Columbia College in New York City. Samuel Langley, president of that large, open-door organization, captured in his welcoming remarks the sense of community that the association provided to isolated researchers.[17] Specifically, he reminded his colleagues that many of them had come to their first meetings "as solitary workers in some subject for which they had met at home only indifference." But they discovered at the meetings other scientists "caring for what they cared for, and found among strangers a truer fellowship of spirit then their own familiar friends had afforded." Michelson found his "fellowship of spirit" in Section B, Physics, one of eight disciplinary divisions available to the 729 members in attendance. Section B, established in 1882, constituted the only national coalition of physicists. During the week-long meeting, the association elected Michelson to be the new vice president in charge of the section. For the next 12 months, Michelson, at age 34, served as the spokesman for the loose-jointed but aspiring American physics community.

Michelson and Morley jointly presented two of the 38 papers read in Section B. One dealt with the relative velocity of the Earth and the ether, and the other covered the method for establishing a standard of length. A few days after the close of the meeting, *Science* reported that "the most important paper" of Section B was Michelson and Morley's discussion of a standard of length.[18] The magazine devoted a full paragraph to characterizing the results. As for their ether paper, *Science* labeled it "a second paper of great interest" and summarized it in only a few lines.

The opinion of AAAS members on the relative value of the two research projects was apparently shared by the leadership of the National Academy of Sciences—the other main, but much smaller and more exclusive, scientific society in the United States. In early November 1887, the Academy invited Michelson and Morley to the annual "Scientific session" to present their latest thoughts on establishing a standard of length.[19] Of the 22 papers read at this meeting, held again at Columbia College, theirs was the only one by nonmembers. The audience was obviously impressed: Michelson was elected a member the next year.

In late December, Michelson and Morley presented their standard-of-length paper to one other appropriate audience, the Civil Engineers' Club of Cleveland. Both men were members of this regionally active group, which was certain to appreciate the practical implications of the standard-of-length research and the interferometer itself. Morley actually read the paper during the evening meeting, but Michelson participated in the discussion afterwards. "Permit me to state," Michelson commented, "that Professor Morley has given me more than my due in attributing so large a share of this work to me. Without his assistance, our present results would never have been attained."

The AAAS and the NAS did more than provide national forums for airing results. The two societies also financed a limited amount of new research. Faced with the expense of precision instruments, Michelson had emerged as one of the nation's most active fund raisers for science.[20] Dollars from the NAS's Bache Fund helped build the Cleveland interferometer. The Bache board of directors matched $500 they had awarded Michelson in March 1887 with an equal amount in late July. These were sizable sums in a time when a person could have his horse shod or buy a bushel of potatoes for about $1. Michelson and Morley supplemented the latter grant with one of the first appropriations ever made by the AAAS. During the August meeting the council of the association allotted the two men $175 "to aid them in the establishment of a standard of length."

Michelson and Morley published their interferometer findings on both the ether drift and the standard of length in the *American Journal of Science*. This multidisciplinary journal, published in New Haven, Connecticut, and edited by James and Edward Dana, provided publishing physicists with their only serious domestic outlet; the *Physical Review* was still six years in the future. Through the efforts of two associate editors, physicists Trowbridge and Barker, the *Journal* managed to carry the best products of American physics. In addition, it kept the community posted on international publications. Throughout 1887, for example, Trowbridge and Barker presented abstracts of articles from foreign journals such as *Annalen der Physik und Chemie*, *Comptes Rendus*, the *Philosophical Magazine* and *Nature*. The *Journal*'s section on "Scientific intelligence" added reports of domestic and foreign meetings as well as reviews of physics books.

Few Europeans read the *American Journal of Science*, so to ensure that their findings reached Europe, many American physicists published or reprinted their articles in foreign journals. Their favorite outlets were British—the *Philosophical Magazine* and *Nature*. Michelson and Morley arranged for each of their two articles to appear simultaneously in the *American Journal of Science* and the *Philosophical Magazine*. The ether drift paper initially appeared in the two journals in November 1887, while the article on the standard of length came out in December.

Personal problems

The December publication on the standard of length would seem to be an appropriate conclusion to this year in the life of Albert Michelson. The article appears to crown 12 months in which Michelson assumed the top office in the physics section of the AAAS, embarked on research that would lead to a Nobel Prize, and completed the ether drift test that would bring him fame in later times. A seldom mentioned scandal in the fall of 1887, however, marred this otherwise storybook year. It damaged his marriage and disrupted his research. In light of Michelson's personal problems, it is perhaps remarkable that he was able to accomplish so much in 1887.

Dorothy Livingston, Michelson's youngest daughter by his second wife, traces his private life in her biography of him.[21] She explains that tensions riddled his first marriage, to Margaret Heminway. The two had quite different backgrounds, Margaret coming from a wealthy New York family and Michelson born in Prussian Poland but raised in mining towns in California and Nevada. Each was strong willed, Margaret wanting to control those about her and Michelson obsessive about his research. The tensions contributed to, and in turn were heightened by, Michelson's psychological illness that surfaced in the fall of 1885. Morley speculated that the illness was precipitated by overwork on the Fizeau experiment—by "the ruthless discipline with which he drove himself to a task he felt must be done with such perfection that it could never again be called into question." Whatever its cause, this "softening of the brain," as Morley characterized the illness, meant that Michelson had to quit teaching at Case and move to New York for full-time medical care. Morley guessed that Michelson would never work again; Margaret apparently agreed, attempting to have him committed permanently to an asylum. Within a few months, however, he recovered and returned to Case. According to Livingston, he returned a cynical man completely alienated from his wife.

Well aware of the long hours that Michelson was putting into the interferometer during the spring and early summer of 1887, Margaret feared a relapse of his illness. Consequently, she arranged for him to combine the business of the August AAAS meeting with the pleasure of a family vacation in the East. (The family included two sons and a daughter.) When they returned to Cleveland, Livingston points out, they were appalled to discover that the maid had stolen some family valuables and fled. Although she was arrested and most of the stolen items were recovered, this event set the stage for the scandal soon to engulf Michelson.

Scandal. The Michelsons, needing a new maid, hired 19-year-old Ruth Whitfield. After several weeks in the family's employ, Ruth, along with her aunt Emma Whitfield, confronted Michelson at home with a demand: Pay $100 to Ruth and $25 to Emma if he wanted them to keep silent about "improper liberties" he had taken with Ruth. This confrontation occurred on 8 October 1887, a Saturday night. Michelson arranged for the women to meet him at his Case laboratory on Monday morning. With his lawyer and Morley at his side—and with a police detective hidden in an adjoining room—he asked the women to repeat their allegation and demand. When they did, Michelson had them arrested and charged with blackmail.

The *Cleveland Plain Dealer* and *The Leader and Herald* reported on the arrest and the subsequent preliminary hearing.[22] According to their accounts, Michelson's lawyer testified about the Monday morning confrontation, recalling that when he asked what complaint Ruth had with Michelson, Emma replied: "He hugged her, and kissed her, and asked her to go to his room." When he asked what would happen if Michelson did not pay the money, Emma answered, "I'll expose him and make trouble for his family." The women's attorney also had an opportunity to cross-examine Michelson, who denied Ruth's allegation. One newspaper reported a portion of Michelson's testimony:

> "When this occurrence is alleged to have taken place between you and Ruth, was your wife at home?" asked Attorney Kaiser, the defen-

Margaret Heminway, Michelson's first wife. (Photograph courtesy of Dorothy Michelson Livingston and the Michelson Collection, US Naval Academy.)

dants' attorney.

"I believe she was not at home."

"Was not one of their objects in calling on you Saturday night to get Ruth's trunk?"

"They asked for the trunk after making their demands."

"While they were at your house did your wife come to the door?"

"Yes."

"Did you say to her, 'Please retire, I have some private business with these ladies?' "

"I did."

"Where did the conversation occur?"

"In the kitchen."

"Did you caution these women not to speak so loudly lest your wife might hear?"

"I did."

"Did you promise to pay them something?"

"I did."

"How much?"

"One hundred dollars."

"Why did you not pay it at the time?"

"In the first place, I had not the money, and in the second place I had no intention of paying it."

On Wednesday evening, the day after the hearing, a police constable arrested Michelson. According to the newspapers, Ruth Whitfield "swore to an affidavit . . . charging Mr. Michelson with having committed assault and battery upon her on October 5, 6, and 7." At this point, the story dropped from the newspapers. Court records, however, continue the account. The records reveal that the justice of the peace who ordered Michelson's arrest set his bail at $100. Summoned before the same justice three days later along with Ruth Whitfield, Michelson "waived examination," whereupon the justice transferred the case to police court.

Documents from police court disclose that in November the case against Michelson "was called up and dismissed." Likewise, a grand jury report from November indicates that Ruth and Emma Whitfield were not indicted for blackmail. Very likely, the opposing lawyers arranged an exchange whereby Michelson dropped his charge and Ruth Whitfield dropped her countercharge.

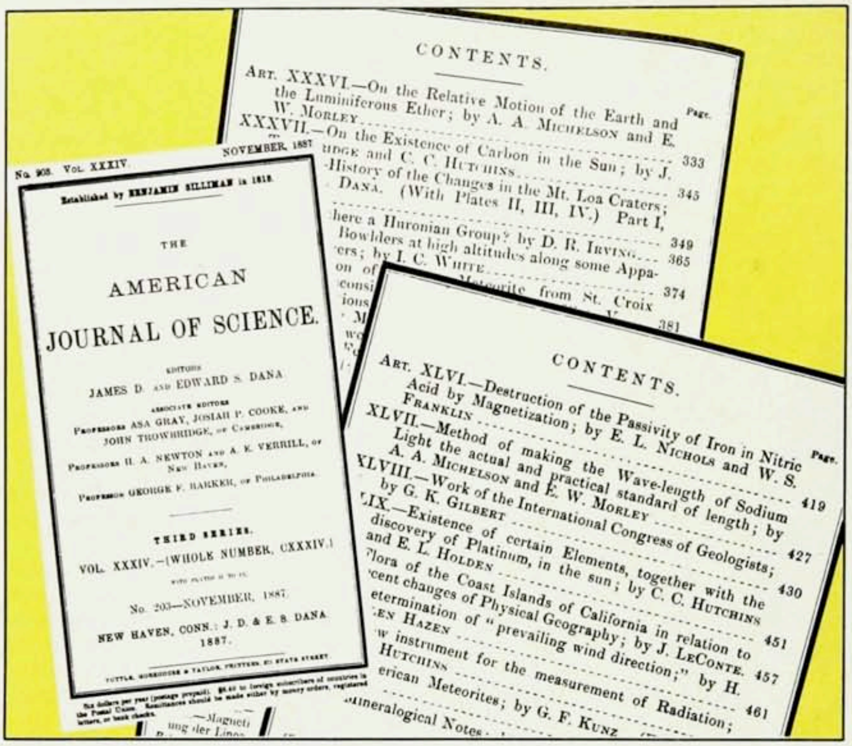
The timing of these events proved inopportune for Michelson. The Civil Engineers' Club had scheduled Morley, and presumably Michelson, to present their standard-of-length paper on the evening of 11 October, the day after the Whitfields' arrest. The club's minutes state that the "paper had been expected" that evening. Instead, Morley and Michelson rescheduled the paper for late December. Also, during the very week that the story was breaking in the newspapers, Michelson's mentor Newcomb was in town along with other dignitaries for the official unveiling of the Lick telescope.

Repercussions. Whereas the details of the episode remain clouded, the aftermath is clearer. The scandal contributed to the collapse of the Michelsons' already foundering marriage. Another decade passed, however, before Margaret obtained a divorce, with the judge finding that Michelson had been "guilty of extreme and repeated cruelty to the complainant."[23]

The episode also disrupted Michelson's interferometer research. Michelson and Morley had planned originally to repeat the ether drift test every few months to guarantee that their initial result was not a quirk. In particular, they wanted to be sure that the negative result did not reflect a chance occurrence of Earth's various motions canceling each other and thus producing a negligible resultant velocity relative to the stationary ether. Actually, there were several reasons for not repeating the test that autumn: Michelson and Morley were moving their laboratory to a permanent site from the temporary quarters they had been using since the fire; they were busy with their classes at the beginning of the academic year; they had begun to suspect, as they expressed it in a "supplement" to their ether drift article, that it was "hopeless" to detect an effect with the interferometer located at the surface of the Earth; and they had shifted their attention to the more tractable standard-of-length investigation. The scandal added to all this and helped scuttle their plans for an immediate repetition of the ether test.

Finally, the scandal seems to have soured the Case administration's attitude toward Michelson. When Case first hired Michelson, Barker asserted that the school would never regret that step. However, by the time Michelson moved on in 1889 to an attractive professorship at Clark University, Morley could report to his father that the administrators "are glad to have him go from the Case School."[24] Personally disappointed, Morley added, "They certainly lose one of the first two physicists in the country in losing Michelson."

Morley realized at an early date what Hasselberg and the Nobel committee came to appreciate in 1907: that Mi-



Journal pages. The November 1887 issue of the *American Journal of Science* contains Michelson and Morley's report on their ether drift experiment. Their article on the use of light as a standard of length is in the December issue.

chelson excelled as a physicist. Indeed, already in 1887 Michelson came near to being the "complete" physicist. That is, he was involved as deeply and creatively as possible for an American of his day with all aspects of the physics enterprise—with the individuals, ideas and institutions of late 19th-century physics. Becoming a consummate physicist, however, exacted a price. Michelson's personal life reeled from psychological distress and marital discord. One wonders what Michelson in later years remembered most about 1887, his achievements in physics or his personal problems. Both contributed to making 1887 a pivotal year for Michelson.

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22. The Leader and Herald (Cleveland), 11 October 1887, p. 5; 12 October 1887, p. 5; 13 October 1887, p. 8; 16 October 1887, p. 6. Cleveland Plain Dealer, 11 October 1887, p. 8; 12 October 1887, p. 8; 14 October 1887, p. 5; 16 October 1887, p. 15. See also the record from the Justice's Court for Cleveland Township, 12 October 1887, and the Court of Common Pleas "Journal," 17 November 1887, Cuyahoga County Archives, Cleveland, Ohio; "Police Court case records," 22 November 1887, Western Reserve Historical Society, Cleveland, Ohio.
23. *Decree of Divorce of Margaret H. Michelson from Albert A. Michelson*, Michelson Collection, Nimitz Library, US Naval Academy, Annapolis, Md.
24. E. W. Morley, letter to S. B. Morley, 2 June 1889, in *Science in Nineteenth Century America*, N. Reingold, ed., Hill and Wang, New York (1964), p. 313. □