# Michelson on Measurement

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At various times A. A. Michelson attributed to an unnamed physicist the remark ". . . the future truths of Physical Science are to be looked for in the sixth place of decimals." The circumstances surrounding this famous comment are related, and the hypothesis is offered that it was Maxwell, or possibly Kelvin, whom Michelson was quoting.

IT is commonplace, when physics teachers begin a discussion of "modern physics," to refer to a statement made in the 1890's by Albert A. Michelson on the direction physics was to take in the future. As often as not they begin with such words as "A famous physicist said · · ·," or "Michelson said · · ·," and end with the words "the future of physics lies in accurate measurement," or "there is nothing left to discover." The quotation is seldom the same, and even the textbooks disagree, one at least being in error by an order of magnitude. Just what did Michelson say? And when and under what circumstances did he make his famous, but vaguely recalled, statement? Perhaps others would be interested in learning what came to the author's attention more or less by accident.

By way of background it might be recalled that Michelson, having studied and taught at the Naval Academy, taught from 1882 until 1889 at the Case Institute of Technology where he had done outstanding research in optics. While in Europe in 1881, on leave from Case, he had invented his interferometer and had made his first attempt to detect the motion of the earth through space. Upon returning, he made a precise determination of the velocity of light, one, indeed, not improved upon until he did it in 1927. After having made quantitative measurements on the velocity of light in several media, other than air, with the result that the difference between group and phase velocity became noticed, he began in 1885 his famous collaboration with Morley on the effect named after them. The final results, obtained in 1887, involved equipment which would have revealed a shift in the interference fringes equal to about one-tenth of a fringe. In 1888–1889 he began preparations to calibrate the standard meter in terms of light waves, a task he finally completed in 1892–1893. For one year, 1889–1890, he was at Clark University. Next he went to the University of Chicago where he became Professor of Physics and Chairman of the Department of Physics. Here he continued his refined measurements based on interferometer techniques. One of his tasks in connection with his position was to prepare a description of the department for the annual *Register* (catalog) of the University. During the first year the description remained of a more-or-less perfunctory sort, but in 1892 the introductory remarks were changed. The entire introduction to the course description is most enlightening and gives a good insight into Michelson's philosophy of physics education, but only a portion can be quoted here.

"Within the last twenty years the teaching and practice of Physics has undergone a revolution more complete than that of any of its sister sciences. This result may be attributed, to a very great extent, to the enormous development of its applications to electrical industries. No other industrial application since the invention of the steam-engine has so enhanced the appreciation of the importance of exact knowledge, or given a greater impetus to the search for new truths in the unexplored regions on the borderland of science.

"So closely interwoven are the advances in pure science and its applications that it is difficult to say which has been of greater service to the other, but it is evident that it is ill-advised to ignore the powerful stimulus furnished by the practical development of scientific ideas as it is to belittle the influence which theoretical and experimental science have had on the world's material prosperity.

"While it is never safe to affirm that the future

of Physical Science has no marvels in store even more astonishing than those of the past, it seems probable that most of the grand underlying principles have been firmly established, and that further advances are to be sought chiefly in the rigorous application of these principles to all the phenomena which come under our notice.

"It is here that the science of measurement shows its importance—where quantitative results are more to be desired than qualitative work. An eminent physicist has remarked that the future truths of Physical Science are to be looked for in the sixth place of decimals.

"In order to make such work possible, the student and investigator must have at his disposal the methods and results of his predecessors, must know how to gauge them, and to apply them to his own work; and especially must he have at his command all the modern appliances and instruments of precision which constitute a well-equipped laboratory—without which results of real value can be obtained only at immense sacrifice of time and labor."[1]

The same words appeared in each issue of the *Register* from 1892 to 1907, when the format of the *Register* was changed and the introduction to the courses was shortened considerably and the given quotation deleted.

In the light of his previous research, most of which depended on careful measurement and the detection of small effects for significant discoveries, it is easy to understand why Michelson wrote as he did. His measurements of the speed of light are recorded to six significant figures and the base line for one of his velocity measurements was measured as 2049.5253 ft. Certainly his writing is at least consistent with his earlier experiences.

But the story is not yet complete. On July 2, 1894, the seventh University Convocation was held at the Kent Chemical Laboratory Theater. The scheduled speaker was to have been T. C. Mendenhall, a well-known physicist of the day, who in 1889 had been president of the AAAS. Unfortunately, a railroad strike prevented Mendenhall from reaching Chicago, and Michelson was asked to take his place. The occasion was not the annual commencement, but, according to Michelson, was to "celebrate the day which begins the seventh quarter of the work of the University of Chicago and at the same time to tender our grateful recognition of the princely gift of Mr. Ryerson to our University and to science—the Ryerson Physical Laboratory."[2]

In this talk, "Some of the Objects and Methods of Physical Science," Michelson repeated almost verbatim many of the sentences that had appeared earlier in the annual catalog of the University, including the sentence "An eminent physicist has remarked that the future truths of physical science are to be looked for in the sixth place of decimals." From his repetition of the now famous remark, we must conclude that while Michelson is quoting some unnamed scientist, he probably, at least for a time, held similar views himself. The remainder of his speech is in much the same vein. He gives an excellent statement of the purpose of science and of the close relationship between science and practical affairs; he speaks of the wonders of the universe; he hints that among the most important problems of the science of his day are the "constitution of matter, and of the ether, and the true mechanism of light"; and he refers time and again to "quantitative work," to "the science of measurement," and to "accurate experiments." We cannot but conclude that a literal interpretation must be placed on his sixth-decimal-place statement. In fact, Michelson later expressed regret at having spoken as he did,[3,4] from which we may infer that his words were to be interpreted at face value.

If, as Michelson says, he is quoting an eminent scientist of the day, who was this man? Millikan, who for many years was associated with Michelson in the same department, suggests it may have been Lord Kelvin.[3,4] In his presidential address to the British Association in 1871, we find that Kelvin did say:

"Accurate and minute measurement seems to the non-scientific imagination a less lofty and

[1] *The Annual Register* (The University of Chicago, Chicago, 1901–1902), p. 270.

[2] Albert A. Michelson, *Quarterly Calendar* (The University of Chicago, Chicago, August, 1894), Vol. 111, No. 2, pp. 12–15.

[3] Robert A. Millikan, Sci. Monthly **48**, 17 (1939).

[4] Robert A. Millikan, *The Autobiography of Robert A. Millikan* (Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1950), p. 23.

dignified work than looking for something new. But nearly all the grandest discoveries of science have been but the rewards of accurate measurement and patient long-continued labour in the minute sifting of numerical results." [5] He goes on to say "Faraday's discovery of specific inductive capacity . . . was the result of minute and accurate measurement of electric forces. . . . Joule's discovery of thermo-dynamic law was based on a delicacy of thermometry which seems simply impossible to some of the distinguished chemists of the day. . . . Andrews' discovery of the continuity between gaseous and liquid states was worked out by many years of laborious and minute measurement in various subjects." Perhaps then, it was Kelvin whom Michelson had in mind, even though in 1893 Kelvin says," . . . we must not fold our hands and think or say that there are no more worlds to conquer for electrical science." [6] This hypothesis is supported by the fact that both Kelvin and Michelson make reference to the development of the electrical industry.

However, curiously enough, in the same year that Kelvin made his statement and only two months later, we find a comment from James Clerk Maxwell that contains reference to "decimal place." Speaking at his introductory lecture given at Cambridge University in October, 1871, Maxwell says:

"This characteristic of modern experiments—that they consist principally of measurements,—is so prominent, that the opinion seems to have got abroad, that in a few years all the great physical constants will have been approximately estimated, and that the only occupation which will then be left to men of science will be to carry on these measurements to another place of decimals.

"If this is really the state of things to which we are approaching, our Laboratory may perhaps become celebrated as a place of conscientious labor and consummate skill, but it will be out of place in the University, and ought rather to be classed with the other great workshops of our country, where equal ability is directed to more useful ends.

" . . . But the history of science shows that even during the phase of her progress in which she devotes herself to improving the accuracy of the numerical measurement of quantities with which she has long been familiar, she is preparing the materials for the subjugation of the new regions, which would have remained unknown if she had been contented with the rough methods of her early pioneers. I might bring forward instances gathered from every branch of science, showing how the labour of careful measurement has been rewarded by the discovery of new fields of research, and by the development of new scientific ideas . . . ." [7]

In the second paragraph of the quotation, Maxwell deprecates the state of affairs which demands precision measurement; yet in the last paragraph, he appears to justify the practice of improving accuracy.

Although Michelson's colleague, R. Millikan, suggests that Kelvin was the physicist quoted by Michelson, the words of Maxwell are more nearly like those of Michelson. Could it be that Michelson, twenty-one years later, paraphrases a mixture of the Kelvin-Maxwell writings? Certainly Michelson was well aware of the writings of both Kelvin and Maxwell; each is fitted by Michelson's adjective "eminent." If Michelson had in mind a single scientist, as in fact he states, one can hypothesize that it was Maxwell in view of Maxwell's use of the words "decimal place." Still, the writer is not satisfied that the present evidence fully clears up the mystery, and he, for one, would be pleased to hear from anyone possessing additional knowledge of the matter, which although perhaps bordering on the trivial seems nonetheless to have attracted wide interest.

[5] Lord Kelvin, *Popular Lectures and Addresses* (Macmillan and Company, Ltd., London, 1894), Vol. II, pp. 156 ff.

[6] Lord Kelvin, Nature **49**, 137 (1893).

[7] J. C. Maxwell, *The Scientific Papers of James Clerk Maxwell* (Cambridge University Press, New York, 1890), Vol. 11, p. 241.