brightness is equal to that of Saturn, it follows (from the inverse-square law of the attenuation of brightness, already established by Bouguer) that Vega must be $(3600/17)(720/\pi)$, or 48,500, times as far from the sun as Saturn is. Moreover, since Saturn is known to be 9.5 times as far from the sun as the earth is, it follows that the distance to Vega should amount to $9.5 \times 48,500$, or some 460,000 astronomical units.

Although this value represents only about a quarter of the actual distance of Vega, first measured trigonometrically by F. G. W. Struve in 1837 (the underestimate resulting from Vega's being intrinsically much brighter than the sun), Michell's value was the first realistic estimate of the distance to any star.

Michell was apparently a man of wide interests, including music. Tradition has it that William Herschel was a frequent guest at Thornhill during his years as a young musician in Yorkshire, and he is even said to have received his introduction to mirror grinding from Michell. There is, however, no real evidence that Herschel turned to astronomical observation before his move to Bath some years later; and the story of his apprenticeship with Michell may, therefore, be apocryphal.

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Zdeněk Kopal

MICHELSON, ALBERT ABRAHAM (*b.* Strelno, Prussia [now Poland], 19 December 1852; *d.* Pasadena, California, 9 May 1931), *physics, optics, metrology.*

Precision measurement in experimental physics was Michelson's lifelong passion. In 1907 he became the first American citizen to win a Nobel Prize in one of the sciences, being so honored "for his precision optical instruments and the spectroscopic and metrological investigations conducted therewith." Michelson measured the speed of light in 1878 as his first venture into scientific research, and he repeatedly returned to the experimental determination of this fundamental constant over the next half century. Never fully satisfied with the precision of former measurements, he developed and took advantage of more advanced techniques and tools to increase the accuracy of his observations. He died, after several strokes, during an elaborate test of the velocity of light in a true partial vacuum over a mile-long course at Irvine, California; but the value later published by his colleagues ($299,774 \pm 11$ km./sec.) was probably less precise than Michelson's own optical determination over a twenty-two-mile course between mountains in southern California during 1924–1926 ($299,796 \pm 4$ km./sec.).

Born to parents of modest means in disputed territory between Prussia and Poland, Michelson at the age of four emigrated with his parents, Samuel and Rosalie Michelson, to San Francisco via New York and Panama. The elder Michelson became a merchant to gold-rush miners in California and later in Virginia City, Nevada, while his son was sent after the sixth grade to board first with relatives in San Francisco and then with Theodore Bradley, the headmaster of Boys' High School there. Bradley seems to have aroused young Michelson's interest in science and to have recognized and rewarded his talents in the laboratory. At Bradley's suggestion Michelson competed for a state appointment to the U.S. Naval Academy; but when three boys tied for first place in the scholastic examination and another was appointed, young Michelson decided to take his case, with a letter of recommendation from his congressman, to the White House. In 1869 he traveled to Washington, saw President Grant, and gained his appointment to Annapolis.

Graduating with the class of 1873, Michelson went to sea for several cruises before being reassigned to the academy as instructor in physical sciences. On 10 April 1877 Michelson married Margaret Heminway from a prosperous New York family; this marriage lasted twenty years and produced two sons and a daughter.

While teaching physics in 1878, Michelson became interested in improving upon Foucault's method for measuring the speed of light terrestrially. In July 1878, with a $2,000 gift from his father-in-law, Michelson was able to improve the revolving-mirror apparatus and to perfect his experiment—the fourth terrestrial measurement of the speed of light. He was preceded by Fizeau, Foucault, and Cornu. Simon Newcomb, superintendent of the Nautical Almanac Office, became interested in his work. In consequence, his first scientific notices and papers were published in 1878–1879, and he began to collaborate with Newcomb on a government-sponsored project to refine further the determination of the velocity of light. He obtained a leave of absence to do postgraduate study in Europe during 1880–1882. He studied with Helmholtz in Berlin, with Quincke in Heidelberg, and with Cornu, Mascart, and Lippman in Paris.

In the winter of 1880–1881, while working in Helmholtz' laboratory, Michelson thought of a means to try a second-order measurement of Maxwell's suggestion for testing the relative motion of the earth against the ubiquitous, if hypothetical, luminiferous ether. Drawing on the credit that Alexander Graham Bell maintained in his account with the Berlin instrument makers Schmidt and Haensch, Michelson designed an apparatus called an interferential refractometer, which he then used to test for relative motion, or an "aether-wind," by comparing the speed of two pencils of light split from a single beam and caused to traverse paths at right angles to each other upon a base that could be rotated between observations. At different azimuths it was expected that the recombined pencils forming interference fringes would shift past a fiducial mark and thereby give data from which could be calculated the "absolute motion" of the earth, with respect to the ether or the "fixed" stars, as it hurtles through space. This first ether-drift experiment was tried in Berlin, then at the Astrophysicalisches Observatorium at Potsdam, with disappointingly null results. The instrument itself was amazingly sensitive and versatile; but errors in experimental design, pointed out by A. Potier and later by H. A. Lorentz, together with the null results themselves and the theoretical difficulties with regard to what was meant by "absolute velocity," later led Michelson to consider the experiment a failure. The hypotheses of A. J. Fresnel concerning a universal stationary ether and of G. G. Stokes concerning astronomical aberration were thus called into question.

The undulatory theory of light as generally accepted in the 1880's simply assumed a luminiferous medium. This "aether" must pervade intermolecular spaces, of both transparent and opaque materials, as well as interstellar space. Hence, it should be at rest or stationary in the universe and therefore provide a reference frame against which to measure the earth's velocity. Michelson boldly denied the validity of this hypothesis of a *stationary* ether, but he always maintained the need for some kind of ether to explain the phenomena of the propagation of light. Ad hoc hypotheses soon seemed necessary to explain why no relative ether-wind or relative motion appeared to be detectable in Michelson's interferometer at the surface of the earth. This curious puzzle piqued the interest of Lorentz, W. Thomson (later Lord Kelvin), and FitzGerald, among others.

In 1881 Michelson resigned from active duty, and the next year he joined the faculty of the new Case School of Applied Science in Cleveland, Ohio. There he set up improved apparatus, helping to check Simon Newcomb's velocity-of-light measurements and testing various colored lights for indexes of refraction in various media. In 1885 Michelson began a collaborative project with Edward W. Morley of Western Reserve, a senior experimentalist (and primarily a chemist) with an elaborate laboratory. Their first effort, undertaken at the suggestion of W. Thomson, and of Rayleigh and Gibbs, was to verify the Fizeau experiment, reported in 1859, that supposedly had confirmed Fresnel's drag coefficient by comparing the apparent velocities of light moving with and against a current of water. This "ether-drag" experiment worked out well and corroborated the suppositions of Fresnel, Maxwell, Stokes, and Rayleigh concerning astronomical aberration and an all-pervasive immaterial luminiferous medium.

Michelson and Morley next redesigned the 1881 ether-drift experiment to increase the path length almost tenfold and to reduce friction of rotation by floating a sandstone slab on a mercury bearing. During five days in July 1887 Michelson and Morley performed their test for the relative motion of the earth in orbit against a stationary ether. Their results were null and so discouraging that they abandoned any effort to continue with the tests they intended in the following autumn, winter, and spring. The sensitivity they had achieved with this new interferometer, about one-fourth part in one billion, was its own reward, however; and both innovators began to think of other uses for such instruments. Although the experimenters quickly forgot their disappointment, theorists, and notably FitzGerald, Larmor, Lorentz, and Poincaré, made much of their failure to find fringe shifts and to corroborate Fresnel and Stokes's wave theory of light.

Michelson accepted an offer in 1889 to move to the new Clark University at Worcester, Massachusetts. Concurrently he began to carry out a monumental metrological project that he and Morley had envisioned to determine experimentally the length of the international meter bar at Sèvres in terms of wavelengths of cadmium light. Adapting his refractometer as a comparator for lengths that could be reduced through spectroscopy and interferometric techniques to nonmaterial standards of length, Michelson found in 1892–1893 that the Paris meter bar was equal to 1,553,163.5 wavelengths of the red cadmium line. So elegant were the success and precision of this project that Michelson became internationally famous.

In 1893 Michelson moved to the new University of Chicago to head its department of physics. There he began to develop his interests in astrophysical spectroscopy. Diffraction gratings, a new harmonic analyzer, and the echelon spectroscope, as well as a large-scale vertical interferometer, were designed by and built for Michelson around the turn of the century. He was clearly recognized as one of the foremost experimental physicists of the nation and was invited to give the Lowell lectures at Harvard in 1899, later published as *Light Waves and Their Uses* (Chicago, 1903). Also in 1899, Michelson remarried, having been divorced, and took as his second wife Edna Stanton, who bore him three daughters.

When Einstein's three famous papers of 1905 appeared, one of which inaugurated the special theory of relativity by dispensing with the idea of an ether and by elevating the velocity of light into an absolute constant, Michelson was much too busy with prior commitments and with receiving honors to pay much heed.

The relation between Michelson's experimental work and Einstein's theories of relativity is complex and historically indirect. But the influence of his ether-drift tests on Lorentz, FitzGerald, Poincaré, W. Thomson, Lodge, Larmor, and other theoreticians around 1900 is less problematic and quite direct. Although scholars continue to debate the role of his classic ether-drift experiment, Michelson himself in his last years still spoke of "the beloved old ether (which is now abandoned, though I personally still cling a little to it)." He advised in 1927 in his last book that relativity theory be accorded a "generous acceptance," although he remained personally skeptical.

From 1901 to 1903 he had served as president of the American Physical Society, and in 1907 he received the Copley Medal from the Royal Society (London) in addition to the Nobel Prize. In all, during his half-century as an active scientist he was elected to honorary membership in more than twenty-five societies, was awarded eleven honorary degrees, and received seventeen medals. In 1910–1911 he served as president of the American Association for the Advancement of Science, and from 1923 to 1927 he presided over the National Academy of Sciences.

During World War I, Michelson returned to the navy as a sixty-five-year-old reserve officer. He helped perfect an optical range finder and demonstrated tolerances for imperfections in striated optical glasses. After the war the Eddington eclipse expedition of 1919 made Einstein and relativity theory almost synonymous with esoteric modern science. Although legend has much inflated the role of the Michelson-Morley experiment in supposedly providing the basis for Einstein's first work on the principle of relativity applied to electrodynamics, Michelson's corroborations of the speed of light as a virtual constant did in fact prove significant equally for the special and for the general theories of relativity.

Early in the 1920's Michelson began to spend more time in California at Mt. Wilson, in Pasadena, and at the California Institute of Technology. Besides teaching, his main work for almost a decade had been to perfect ruling engines for the production of better diffraction gratings. But administrative duties at the University of Chicago also weighed heavily upon him. In southern California, he could work and play in several well-equipped laboratories and also indulge his interest in tennis, billiards, chess, and watercolor painting. Tests for the rigidity of the earth (or earth-tide experiments) were followed by work with H. G. Gale toward an elaborate test near Chicago for the effect of the earth's rotation on the velocity of light. Other studies of the application of interference methods to astronomical problems led to the construction in 1920 of the celebrated stellar interferometer on the Hooker 100-inch telescope that measured the amazing angular diameter of α Orionis (Betelgeuse), which was found to have a disk subtending 0.047″ arc, or approximately 240 million miles in diameter. Still other tests and a geodetic survey under Michelson's supervision in southern California prepared the way for a measurement of the velocity of light between mountain peaks. The Mt. Wilson to the San Jacinto Mountains measurement (eighty-two miles) was scuttled because of smog in 1925; the Mt. Wilson to Mt. San Antonio measurement (twenty-two miles) was completed in 1926, and the value remains one of the best optical determinations ever made.

Meanwhile, George Ellery Hale, director of the Mt. Wilson Observatory, had invited to southern California Michelson's friend and successor at Case, Dayton C. Miller, who had worked with Morley on other ether-drift tests in 1900–1906 and had achieved eminence in acoustics. Miller was supposed to perfect the original Michelson-Morley experiment for all seasons and at a 6,000-foot altitude. After many vicissitudes he did so in 1925–1926 and, to the consternation or delight of a divided profession, Miller announced in his retiring address as president of the American Physical Society that he had finally found the absolute velocity of the solar system: about 200 km./sec. toward the head of the constellation Draco! This challenge spurred Michelson to take up ether-drift tests once again. In conjunction with F. G. Pease and F. Pearson, several very elaborate interferometers were built and operated briefly from 1926 through 1928 but to little avail. Neither Michelson nor his team—nor any other experimentalists later in the 1920's—were able to corroborate Miller's slight but positive results; and so Einstein stood verified largely on the authority of Michelson's reiterated word.

Michelson's second book, *Studies in Optics*, was published in 1927, the year before the Optical Society of America dedicated its annual meeting to him on the fiftieth anniversary of his scientific career. Michelson had used "Light Waves as Measuring Rods for Sounding the Infinite and the Infinitesimal," as the title of one of his last papers. When he died in 1931, he was hardly less a believer in the wave theory of light and its concomitant ether. Although he supported Einstein with few reservations, he was secure in the knowledge that he had indeed sounded the nature of light and found its field both infinite and infinitesimal.

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Loyd S. Swenson, Jr.

MICHURIN, IVAN VLADIMIROVICH (*b.* Dolgoye, Russia [now Michurovka, U.S.S.R.], 28 October 1855; *d.* Michurinsk, U.S.S.R., 7 June 1935), *plant breeding*.

For a complete study of his life and work, see Supplement.

MIDDENDORF, ALEKSANDR FEDOROVICH (*b.* St. Petersburg, Russia, 6 August 1815; *d.* Khellenurme [now Estonian S.S.R.], 16 January 1894), *biogeography*.

Middendorf graduated from the Third Petersburg Gymnasium, of which his father was director, and, in 1837, from Dorpat University with an M.D. For two years he studied zoology, botany, and geognosy at universities in Germany and Austria. In 1839 and 1840 he taught zoology at Kiev University. During the summer of 1839, he traveled to the Kola Peninsula with Karl Ernst von Baer.

In 1844 Middendorf completed a two-year journey to northern and eastern Siberia commissioned by the St. Petersburg Academy of Sciences. In 1845 he was elected to membership in the Academy, and in 1852 he became its permanent secretary. A sharp decline in his health obliged Middendorf in 1865 to relinquish his post as academician, but he was retained as an honorary academician. Middendorf subsequently resided at his estate, Khellenurme, where he completed a multivolume account of his Siberian journey and also journeyed to the Baraba Steppe in Western Siberia, and to the Fergana Valley in Central Asia.

Middendorf gave a brilliant geographical description and an ecological and geographical analysis of the fauna of Siberia, in which he examined in detail the