Albert Abraham Michelson

Some experiments change the face of a subject, and some experiments do that many times over. Albert Michelson built his interferometer in order to determine the effect of Earth's rotation on the speed of light. The null result supported the crucial assumption in Einstein's special theory of relativity and was the final nail in the coffin of classical mechanics. The interferometer is also being currently used in the detection of gravitational waves, which is poised to change the face of astrophysics.

The simplicity and sensitivity of his interferometer have affirmed Michelson's name in the physicists' hall of fame of all time. It was also one of the pioneering physics experiments that placed the United States of America in the map of world science.

Albert Abraham Michelson was born in 1852 to a Jewish family in Strelno, in the Posen province of the then Kingdom of Prussia (presently called Strzelno and located in Poland). His family emigrated to the United States in 1855. As a child, he grew up in the mining town of Murphy's Camp, California, and continued to study in public schools, staying with his aunt in San Francisco, while his family settled in Virginia City, Nevada. At the age of 17, he got a special appointment as a midshipman from the US President at the Naval Academy in Annapolis, Maryland. After graduating and spending two years at sea, he returned to the Naval Academy, where he taught for four years.

It was here, around 1877, that an event transformed his life (apart from the fact that he got married that year). Michelson was preparing for a demonstration of Foucault's method for determination of the velocity of light. This was a modified version of Fizeau's method, in which the path of a light wave and its return path was continually chopped by a rotating toothed wheel, whose speed was adjusted to give a bright image, implying that the frequency of the wheel rotation had matched the time interval between the passing of light wave and its return. Foucault had used a rotating mirror in place of the wheel, making the observation of the bright image less subjective. However, the limited length of the light-path (roughly 20 meters) was a hindrance in obtaining a good measurement accuracy. Michelson realized that if he collimated the beam – which he managed by a clever arrangement of the optical elements – he could get a longer optical path-length and thus a better accuracy in the measurement. He published his results in 1879, reducing the velocity of light from 299990 to 299944±51 km/s (which is within about 0.05% of the modern value). It was a small but crucial difference because of its importance in the theory of electromagnetism. (It was only in 1888 that Hertz's experiment decisively showed that light was indeed an electromagnetic wave.)

When Michelson joined the US Naval Observatory in 1879, his mentor, the astronomer Simon Newcomb, encouraged him to further pursue this experiment. Michelson's experiments were partly aided by a generous sponsorship from his father-in-law. Within three years, he reduced the speed to 299853±60 km/s. By 1926, he was able to increase the optical path-length to 22 miles, using the distance between the Mt. Wilson Observatory and Mt. Baldy as a baseline, and refine the measurement to 2997964 km/s.

Michelson's experimental genius was recognized early on. Although Newcomb supported his experiments, many others felt that Michelson's talents deserved a better setup than the Naval Observatory, which did not have the mandate of carrying out fundamental research. Josiah Gibbs, the famous theoretical physicist, suggested that Michelson should "go to sea for some years or will be lost to science", and that he should visit Hermann von Helmholtz in Germany, who was also working on electromagnetic waves at that time. American students of science those days often went to Europe for further studies.

In Berlin, he worked at the Physics Institute, which was headed by Helmholtz. It was there that he came up with the basic design of the interferometer that bears his name. A beam of light was split and sent along two perpendicular paths. After bouncing off two mirrors, the beams were then recombined and an interference pattern was produced. Imagine a number of soldiers marching in a rhythm. If they are divided into two parts and sent to march along two equal long paths, after which their steps are examined, if they are in sync or not, then any small difference between the long paths, or a difference in their speeds in those two perpendicular paths would be noticed. This was the basic and elegant idea, and Michelson wanted to use it to test the hypothesis of ether. Michelson's initial experiment in January 1881 in the basement of the institute in Berlin failed because of the vibrations from the traffic outside. Then he repeated the experiment in a tower of the astronomical observatory in Potsdam, and it gave a null result. This was already a sign of what was going to come in the future when he would make the experiment more sophisticated and accurate.

By the time he came back from Europe, he had been exposed to some of the most famous experimentalists and theoreticians of nineteenth century Europe, and in particular, the ideas of conducting experiments to nail down the hypothetical medium – 'ether'. Upon returning to USA in 1882, he was offered a position at the Case Institute of Technology, Cleveland, Ohio. He attended a couple of conferences in Montreal and Baltimore in the next two years, along with a colleague from Western Reserve University (now part of Case Western Reserve University), Edward Williams Morley, in which the connection of light with electromagnetic waves was discussed in earnest, along with the implications for the existence of ether. The Baltimore meeting, in particular, was attended by the stalwarts of those days, including Lord Kelvin and Lord Rayleigh.

During the train-ride back to Cleveland from Baltimore, Michelson and Morley planned a new set of experiments to address the issue of ether-drift. Morley's collaboration was crucial in making the experiment more accurate than Michelson's earlier versions. They also worried about the possibility that there could be local 'pockets of ether' on the Earth's surface, which could be locally still and Earth's rotation may not have any effect on the experiment. As a matter of fact, Michelson kept worrying about this aspect till the end, when he extended his experiment to mountain tops.

Their work however stalled, because of problems at Michelson's home. Michelson's preoccupation with research often bordered on the obsessive. His relation with his wife was strained, and his wife even tried to commit him to an asylum. Dorothy Michelson Livingston, his daughter from his second marriage, later wrote about his father aloofness that he was "like a very important guest in the house" [1]. At the same time, he also had the reputation of being an accomplished painter and violinist. He was so good in billiards that his opponents thought that his knowledge of physics gave him an unfair advantage. Michelson's doctor, Alan Hamilton, a neurologist, believed that there was nothing wrong with him and a time off from his family would help. But the situation had already harmed Michelson's reputation to the extent that he temporarily lost his job at Case, although he was reinstated after a year at a lower salary. Morley offered his lab for their experiment, and Lord Rayleigh's recommendations helped them acquire the required fund for a new interferometer that they completed building by 1887.

Together, they were able to increase the lengths of the 'arms' of the apparatus by making the light beam travel a greater distance, with the introduction of 14 additional mirrors (the original experiment that Michelson had previously conducted in Europe had only two). The sandstone block that served as the base of the apparatus was floated on a pool of mercury, to make the rotation easier. During the experiment, the entire apparatus slowly rotated, and the observer had to slowly walk in step with the apparatus, carefully looking through a telescope whose eye piece was less than 1/4 inch in diameter. Morley later recounted that the patience he and Michelson had to maintain during the experiment constituted some of the most trying moments of his scientific career.

They began their experiments in April 1887, in Morley's darkened basement laboratory. Thousands of observations were carried out over four months, ending in July. All these attempts to detect the effect of ether-drift on the speed of light ended in failure, as they described in a paper published that summer. And the rest is history.

In 1889, Michelson went to Clark University (and married for the second time), and then to the newly started University of Chicago three years later. He was awarded the Nobel Prize in physics in 1907 (*for his optical precision instruments and the spectroscopic and metrological* *investigations carried out with their aid*), the first scientist from the US to receive it.

Besides continuing to improve upon his speed of light measurements, during his later years, at the encouragement of astronomer George Hale of Mt. Wilson Observatory, Michelson became interested in the measurement of the size of stars with his interferometer. Between 1920 and 1925, he was able to measure (along with Francis Pease) the diameter of Betelgeuse, a super-giant star, from the Mt. Wilson Observatory. They determined its size to be roughly 100 times that of the Sun. This method could, however, only measure the size of the largest stars, the giants and supergiants, because of the limitation of the size of the telescope. They measured the sizes of 6 stars, all of them with angular sizes larger than 0.02 arc seconds.

In 1926, he achieved his most accurate measurement of the speed of light (mentioned earlier) with a long baseline. His arc of light split the sky between the Mt. Wilson Observatory and Mt. San Antonio, and it must have been quite a sight for those who witnessed the event. According to Michelson's daughter, "the huge arc lamp that furnished the light beam took nearly all the direct current that Mount Wilson generators could supply. Its powerful violet rays lit up the mountain top with a lurid glow." [1]

In spite of his well-known obsession with work, Michelson found time to pursue other interests. Often, he took his easel to scenic places in the Californian mountains for painting. Light and colours in Nature fascinated him, and once he wrote a paper on 'The metallic coloring of birds and insects' (1911), in which he wondered about the iridescent colours found on their bodies. "The aesthetic side of the subject is by no means the least attractive to me", he said during a lecture at the Lowell Institute in 1899. [2]

Michelson's health deteriorated rapidly in the late 1920s. He resigned from the University of Chicago and moved to Pasadena to work at the Mt. Wilson Observatory. He managed to persuade a wealthy rancher James Irvine Sr. to allow him to conduct an experiment in what is now called the Orange County, California, because it was a vast, flat bean field. (Ironically, the speed limit on the present Michelson Drive is one of the smallest in the city of Irvine!) He wished to measure the light speed in vacuum, and proceeded to build a mile-long evacuated steel pipe for the purpose. His bladder had been removed and he suffered from low blood pressure, spending most of the day lying on the bed. In April 1931, Einstein came to meet him over lunch at his place after hearing about his health. "Michelson attempted to rise from his chair to welcome his guest, but weakness prevented him. It was an emotional meeting for both. Einstein drew a chair up close to Michelson's and they talked to each other..", as recalled by Michelson's daughter [1]. Michelson had to be confined to his bed due to weakened heart condition. His assistants brought in the first set of data from the new experiment on 7th May 1931. He died two days later of a stroke while preparing the draft of a new paper.

In a meeting held in 1928, at Pasadena on the Michelson–Morley experiment, which was attended by Hendrik Lorentz, Michelson was scheduled to speak on his new experiments, and it was the last time he ever spoke in public. By that time, however, new methods had come up to measure the speed more accurately than his figure. Roy Kennedy, who had measured the speed at the Norman Bridge Laboratory, spoke before Michelson. When Michelson's turn came to present his 1926 results from the Mt. Wilson Observatory, he rose to compliment on the precision of Kennedy's experiment, and said, "Your work, Dr. Kennedy, renders my own work quite superfluous. I should not have undertaken it had I known you were doing it so well." [2] He could not have paid a better tribute to his lifelong passion to measure what the poet Robert Frost once called *The Master Speed*:

No speed of wind or water rushing by
But you have speed far greater. You can climb
Back up a stream of radiance to the sky,
And back through history up the stream of time.

Suggested Reading

[1] Dorothy Michelson Livingston, *Master of Light: A Biography of Albert A Michelson*, Chicago University Press, Chicago, USA, 1973.

[2] Robert A Millikan, *Albert Abraham Michelson in Biographical Memoirs*, *National Academy of Sciences* (US), Vol XIX, 1937.

Biman Nath
Raman Research Institute, Bengaluru 560 080
Email: nath.biman@gmail.com