Optics at the U.S. Naval Academy

This is the first of a series of occasional articles about institutions of interest to opticists.

Optics is still alive and healthy at the U.S. Naval Academy, where 100 years ago Albert A. Michelson performed the first in a series of optical experiments of remarkable accuracy.

In the centennial year of the publication of Michelson's paper, "On a Method of Measuring the Velocity of Light,"[1] John R. Smithson of the physics department treated us to a tour of the Academy's facilities and an inspection of the Michelson memorabilia displayed there.

In 1878, five years after graduating from the Academy, Michelson described a modification of Foucault's rotating-mirror apparatus for measurement of the velocity of light. A year later, he reported his first results[2] over an optical path of 304 m: 300,140 ± 480 km/sec, a difference of 348 km/sec from the current value.

The Naval Academy of 1978 enrolls 1300–1400 new students each year and graduates 800–900 students four years later. There were 86 midshipmen enrolled in Michelson's class; 29 graduated in 1873[3]; Michelson ranked ninth in that class.

Figure 1 is a photograph of Michelson taken when he was a midshipman. The curriculum of the time and Michelson's standing in his courses has been compiled in a definitive review article by Bennett *et al.*[4] Their data indicate that Michelson was first in class rank in optics and acoustics, second in heat and climatology, first in drawing, twenty-fifth in seamanship. The curriculum for all students in 1883 and that for physics majors in 1978 have extraordinary similarities, if one overlooks a few latter-day innovations, such as physics of the atom, nuclear physics, and solid-state physics.

In contrast to earlier times, the Naval Academy now permits students to elect a major in one of 18 different areas (seven in engineering, six in the physical sciences, naval architecture, and, in addition, economics, English, history, and political science). All students are required to take at least a year of general physics. This requirement leads to a physics faculty that includes 25 civilian and 10 naval and Marine officers. This makes the Academy's physics faculty one of the largest in any B.S. school (one in which the bachelor's degree is the highest degree awarded) in the country. Approximately five per cent (40–50) of the midshipmen select physics as a major. This number also ranks the Academy at or near the top of the B.S. institutions in the number of graduating physics majors.

Fig. 1. Cadet Midshipman Albert A. Michelson in 1873. Portrait in the *Logbook* of the graduating class of that year at the U.S. Naval Academy, Annapolis, Maryland.

Fig. 2. Michelson Hall at the U.S. Naval Academy. The light path for the original speed-of-light experiments crossed the plaza. Metal disks embedded in the plaza approximate the direction of the propagation.

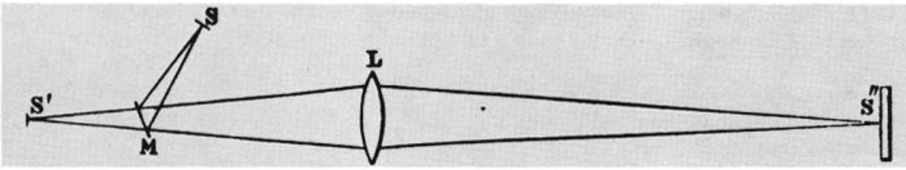

Fig. 3. Schematic diagram of optical paths suggested by Michelson in Ref. 1.

Courses required of physics majors are similar to those of other institutions and include the usual intermediate courses in waves, electricity, mechanics, and atomic physics. Optics is one of five elective courses from which students must choose two. Some 18 students choose optics each year. The course in optics includes such subjects as Fourier-transform treatment of diffraction, concept of partial coherence, interference theory, holography, polarization, and the optics of solids. A well-equipped laboratory is an adjunct to the course. Naturally, every student becomes an expert at aligning Michelson interferometers (one to a student) and at interpreting the output of a scanning instrument. Donald Treacy is the current instructor for the course. He makes excellent use of a variety of instructional equipment in the laboratory, including several Czerny–Turner scanning monochromators, a scanning Fabry–Perot interferometer, a Raman spectrometer, equipment for making holograms and for observing the Zeeman effect, and a set of Schlieren optics.

Research in optics at the Academy is directed toward understanding of rare-earth-doped halides. In addition to Treacy, John Fontanello is active in the program. Equipment for susceptibility measurements, magnetic resonance, and a variety of optical instrumentation including a 2-m Czerny–Turner spectrometer and several double-beam infrared instruments is in use.

The facilities of the physics department as well as the other physical science departments are housed, appropriately enough, in Michelson Hall. The building was dedicated in 1969. John Sanderson reported on the dedication at the time.[5] The building is located near the site of the original speed-of-light experiments. The first experiments were along what was then the north sea wall of the Academy. Figure 2 shows Michelson Hall. Michelson's original light path traversed the plaza. Several filling projects have changed the direction and location of the Severn River.

Michelson's years at the Academy and his later career have been extensively documented. Reference 3 provides an interesting glimpse of life at the Academy from 1869, when Michelson entered as a midshipman, until 1897, when he was transferred from his teaching position to the Nautical Almanac Office in Washington. Reported in this reference are the first two questions on the optics examination given to Michelson's class: (1) "Discuss the undulatory theory of light. What fact proves the emission theory false?" and (2) "Describe Foucault's apparatus for determining the velocity of light." Apparently the inspiration for the original experiment to measure the velocity of light came not from the final examination but from an attempt to give a lecture demonstration of the Foucault method, during which Michelson realized that the position of the rotating mirror (M relative to L in Fig. 3) was critical to the sensitivity of the experiment. In the experiments of Foucault, the distance between L and M was kept small, and the return mirror was concave. Michelson realized that placing the rotating mirror near the focus of lens L would make the return image a stationary one and would allow one to increase the distance, *LS''*, without appreciable loss of intensity.

Michelson described the difficulties with the Foucault experiment in his notebook[6] as follows:

> In this case, L, Fig. 3, served simply to form the image of S, at S'', and S'', the returning mirror, was spherical, the center coinciding with the axis of M. The lens, L, was placed as near as possible to M. The light forming the return image lasts, in this case, while the first image is sweeping over the face of the mirror, S''. Hence, the greater the distance, *MS''*, the larger must be the mirror, in order that the same amount of light may be preserved, and its dimensions would soon become inordinate.

The heliostat used by Michelson for the experiment is pictured in Fig. 4. The electrically driven tuning fork used to calibrate the rotating mirror is shown in Fig. 5. A model of the first rotating mirror is shown in Fig. 6.

Fig. 4. Heliostat used by Michelson to focus scan light on the entrance slit for the first velocity-of-light experiment. The heliostat was borrowed by Michelson from the Army Medical Museum.

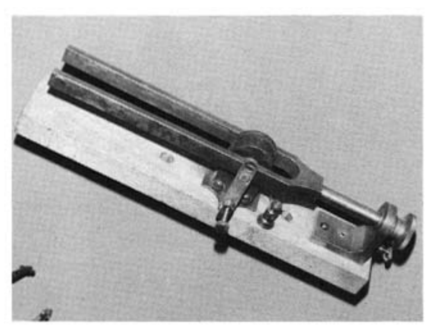

Fig. 5. Electrically driven tuning fork used by Michelson to calibrate the rotating mirror. One prong of the mirror has a steel mirror attached. Beats between the rotating mirror and the tuning-fork mirror are closely observed. The rotation speed for the first set of experiments was 128 revolutions/sec.

The success of these experiments and those that followed is well documented. The 1907 Nobel Prize in Physics was awarded to "Albert A. Michelson for his precision optical instruments and the spectroscopic and metrological investigations conducted therewith."

His major contributions were enumerated on the occasion of the 1928 annual meeting of the Optical Society in Washington. Table 1 gives an outline of these contributions as they appeared in the frontispiece of the meeting program. This meeting was named the Michelson Meeting to honor the semicentennial of the first velocity-of-light experiments. Michelson was present for the meeting, which was held at the National Bureau of Standards, and more than 500 attended, in contrast to an attendance of 100 typical at the time.

Michelson's final contributions to measurement of the velocity of light did not come until the completion of the experiment conducted at the Irvine Ranch near Santa Ana, California. This experiment used an evacuated pipe 1.6 km long to eliminate uncertainties in the index of refraction of air. A portion of the pipe is pictured in Fig. 7.

Science and scientists are fortunate that many records and appreciable parts of Michelson's apparatus have been preserved. The Naval Academy has numerous items on display in Michelson Hall. These include material that has been at the Academy since Michelson's days as well as a wealth of material transferred to the Academy from the Michelson Museum at China Lake, California. In addition, the Academy's Nimitz Library has a large collection of Michelson's papers and photographs. Portions of the collection are on public display.

TABLE 1 Compilation of Michelson's Accomplishments Made on the Occasion of the October 1978 Meeting of the Optical Society of America

1878	Method for measuring the velocity of light.
1879	Determination of the velocity of light.
1881	First experiments on ether drift.
1882	The Michelson interferometer.
1884	Measurement of the velocity of light in water and carbon disulphide.
1886	The influence of the motion of the medium on the velocity of light.
1887	The Michelson-Morley experiment on ether drift.
1891	Measurement of Jupiter's satellites by interference.
1892	The visibility of interference fringes–homogeneity and fine structure of spectral lines.
1893	Comparison of cadmium wave lengths and the length of the international meter.
1897-1898	Separation of the components in the Zeeman effect.
1898	Harmonic analyzer.
1900	The echelon spectroscope.
1913	Analysis of sun-spot cycle.
1914	Measurement of the rigidity of the earth–revealing earth tides.
1915-1916	Ruling, testing, and performance of a 10-inch diffraction grating.
1921	Measurement of the diameter of α-Orionis with interferometer.
1924	New measurements of the velocity of light.
1925	Effect of earth's rotation on the velocity of light.
1928	Repetition of the Michelson-Morley experiment.

Source: Program of the Michelson Meeting of the Optical Society of America, J. Opt. Soc. Am. 18, 143-286 (1929).

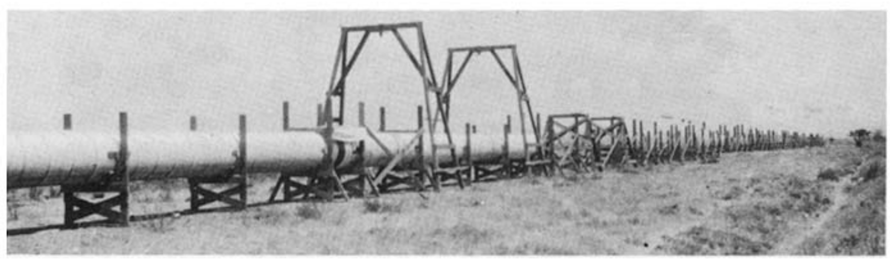

Fig. 7. The center section of the 16-m-long evacuated pipe set up in 1930 on the Irvine Ranch near Santa Ana, California, for Michelson to measure the velocity of light in a partial vacuum.

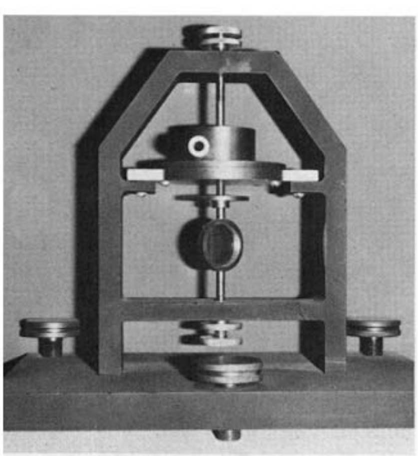

Fig. 6. A replica of the original rotating mirror. The mirror is driven by an air turbine.

Finally, Gerald Calame, chairperson of the physics department at the Naval Academy, reports that there is a vacancy on the faculty for an individual whose research specialties are in optics. There are a set of substantial footsteps to follow in.

John R. Smithson provided much of the information for this article. Some of the material was located in the archives of the Nimitz Library with the help of Alice S. Creighton, the archivist. Figures 1 and 4 are from the archives of the Nimitz Library; Fig. 7 is from the Hale Observatories.

REFERENCES

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3. J. M. Bennett, D. Theodore McAllister, and G. M. Cabe, "Albert A. Michelson, Dean of American Optics–Life, Contributions to Science, and Influence on Modern-Day Physics," Appl. Opt. 12, 2253-2279 (1973).
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6. Facsimile copy of notebook of Albert A. Michelson entitled "Velocity of Light," reproduced by Honeywell, Inc.