Pioneers in Optics: Jean-Bernard-Leon Foucault and Willebrord Snell

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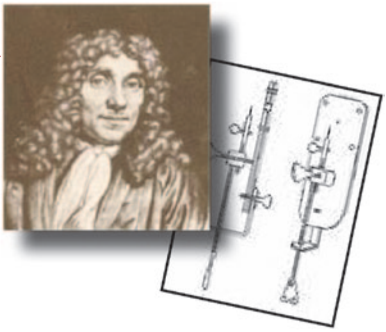

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Jean-Bernard-Leon Foucault
(1819–1868)

Jean-Bernard-Leon Foucault was a French physicist who is considered one of the most versatile experimentalists of the nineteenth century. He is well known for his experiments in optics and mechanics and was involved in the development of a method to measure the speed of light with extreme accuracy. Foucault is most often remembered for proving, with the use of a pendulum, that the Earth rotates on its axis.

On September 18, 1819, Foucault was born in Paris, France, the son of a publisher. He received his early education at home, and he showed youthful promise in mechanics. After obtaining his bachelor of arts degree, Foucault entered medical school but soon abandoned the program. Instead, he began working for Alfred Donne, making preparations for a university medical microscopy course. Because his elementary mathematical and scientific training had been inadequate for his interests, Foucault supplemented it as he became involved with invention and experiment.

Foucault met the French physicist Armand Fizeau in 1839, and the pair worked in close collaboration for almost a decade. Together they took the first detailed pictures of the sun's surface and developed a more precise way to measure the speed of light in 1849. Foucault proved independently that the speed of light in air is greater than it is in water. His other contributions to the field of optics included a method of measuring the curvature of telescope mirrors, an improved technique to silver astronomical mirrors, a method of testing telescope mirrors for surface defects, and the invention of a polarizing prism to orient and manipulate polarized light.

Succeeding Donne as the scientific editor of the French publication *Journal des Débats* in 1845, Foucault's most widely recognized feat was not completed until several years later. While employing a pendulum to create a clock used for controlling telescopes, he stumbled on the idea of applying the technique to prove that the Earth rotates on its axis. Foucault based his proof on Newton's law, which states that when a body is set in motion, it will move in a straight line from its origin, as long as it is not influenced by outside forces. Foucault demonstrated his proof for the first time at the 1851 World's Fair in the Pantheon in Paris. He showed that although the pendulum seemed to change its path during the day, it was actually the floor that was rotating underneath the pendulum. Because the floor is attached to the Earth, it must be the Earth that is rotating.

The gyroscope was another device invented by Foucault to demonstrate the Earth's movement around its axis. The apparatus he designed earned him the Cross of the Legion of Honour and is the basis of the modern gyrocompass. Foucault was given the position of physicist of the Paris Observatory beginning in 1855 and was one of the first to demonstrate the existence of eddy currents generated by magnetic fields, which are sometimes referred to as Foucault currents. Other honors bestowed on him include the Copley Medal of the Royal Society of London, as well as election into the Bureau of Longitudes and the French Academy of Sciences. His successful career was ended prematurely, however, when he suffered a sudden stroke of paralysis and died at the age of 48.

Measuring the Speed of Light. Starting with Ole Roemer's 1676 breakthrough endeavors, the speed of light has been measured at least 163 times by more than 100 investigators using a wide variety of techniques. Finally in 1983, more than 300 years after the first serious measurement attempt, the speed of light was defined as being 299,792.458 kilometers per second by the Seventeenth General Congress on Weights and Measures. Thus, the meter is defined as the distance light travels through a vacuum during a time interval of 1/299,792,458 seconds. In general, however, (even in many scientific calculations) the speed of light is rounded to 300,000 kilometers (or 186,000 miles) per second.

Willebrord Snell
(1580–1626)

Willebrord Snell was an early seventeenth-century Dutch mathematician who is best known for determining that transparent materials have different indices of refraction depending on their composition. Snell was born to an affluent family in Leiden in 1580 and started studying mathematics as a very young man. His father was a scholar and professor of mathematics at the University of Leiden.

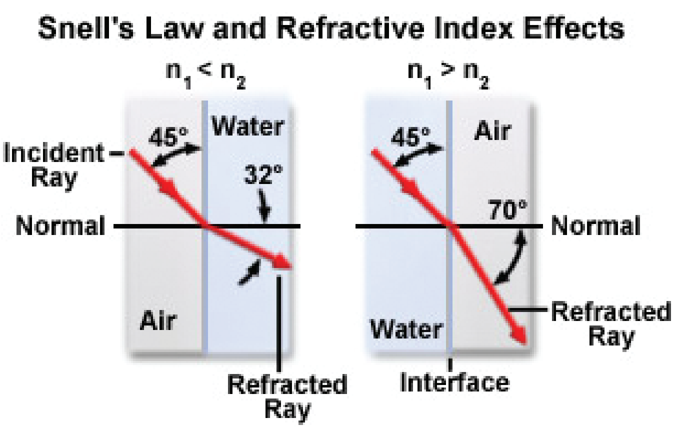
Snell entered the University of Leiden at a relatively young age where he originally studied law. His attention soon turned to mathematics, and he was teaching at the university by the time he was 20 years old. After finishing with his degree at the university, he traveled to eastern Europe and visited most of the major astronomers of the day.

In 1613, Snell succeeded his father as professor of mathematics at Leiden and in 1617, he published *Eratosthenes Batavus*, which explained his methodology for measuring the Earth by triangulation. Snell had difficulty completing his work until the brother barons Sterrenberg took over and finished it with his assistance. This important work wove the foundations of modern geodesy.

Snell also published other works, including his work on comets, and in 1624, he published *Tiphys Batavus*, a work on navigational theories. His work in mathematics allowed him to produce an improved method of calculating approximate values of pi using polygons. This method, using 96-sided polygons, produce a value of pi correct to seven places, a striking improvement to the classical method that yielded only two places.

The laws of refraction of light remain Snell's most important contribution to science, although they were not published until almost 70 years after his death. The Egyptian geographer Ptolemy initiated the study of refraction and described a law to explain the degree of diffraction, even though his results did not always agree with his law. Ptolemy was followed by Arab scientist Alhazen, who also studied refraction but could not predict how far light would bend when entering a medium of greater refractive index.

Snell discovered that a beam of light would bend as it enters a block of glass and that the angle of bending was dependent on the incident angle of the light beam. Light traveling in a straight line into the glass will not bend but, at an angle, the light is bent to a degree proportional to the angle of inclination. In 1621, Snell found a characteristic ratio between the angle of incidence and the angle of refraction. Snell's law demonstrates that every substance has a specific bending ratio—the "refractive index." The greater the angle of refraction, the higher the refractive index for a substance.



Snell's law can be described as follows:

$$n_1 \cdot \sin(\theta_1) = n_2 \cdot \sin(\theta_2)$$

where n represents the refractive indices of material 1 and material 2 and θ are the angles of light traveling through these materials with respect to the normal. There are several important points that can be drawn from this equation. When n_1 is greater than n_2, the angle of refraction is always smaller than the angle of incidence. Alternatively when n_2 is greater than n_1, the angle of refraction is always greater than the angle of incidence. When the two refractive indices are equal ($n_1 = n_2$), then the light is passed through without refraction.

Snell died at the relatively young age of 46 on October 30, 1626, in Leiden. He would never realize that his discovery of the basic laws of refraction would prominently position his name in textbooks on physics and optics.

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