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History of Measurements of the Velocity of Light

The Greeks

The Greeks were not unanimous on whether light moved at a finite or infinite velocity (see text p. 2).

Galileo's attempt

Galileo used lanterns between two hilltops. Saw essentially no travel time. If the distance were, say 2 miles, then the sound distance would be about 10 seconds. He had no reason to believe that the velocity of light was significantly faster than that of sound.

Astronomical measurements

In 1676 **Rømer** made careful measurements of the times at which satellites of Jupiter were eclipsed by the planet. The times observed did not agree with those calculated on the assumptions of a constant period of rotation and of instantaneous transmission of light. Starting at a time when the Earth was at its nearest to Jupiter, the apparent period increased and the eclipses became increasingly later than the calculated times as the Earth receded from Jupiter. Similarly, the period shortened when the Earth was moving toward Jupiter. The observed times were consistent with a finite velocity of light such that the time for it to transverse the Earth's orbit is about 1,000 seconds. Taken with modern values of the size of the Earth's orbit, the derived value of the velocity is 298,000 kilometres per second. It is remarkable that this first measurement was even of the correct order; *the most important conclusion was that the velocity of light is finite*. An English astronomer, **James Bradley** (died 1762), obtained a similar value by the so-called aberration method, based on the apparent motion of stars as the Earth travels in its orbit about the Sun.

Note: This is not true. Roemer never made a measurement from his obervations. He observed a deviation of either 11 minutes or 22 minutes, not the 17 reported here.

"Light: General considerations: VELOCITY OF LIGHT: Astronomical measurements." Britannica Online.
http://www.eb.com:180/cgi-bin/g?DocF=macro/5003/76/16.html

Early terrestrial experiments

In terrestrial experiments by method (1), the beam of light is periodically marked either by interrupting it at regular intervals or by modulating it (alternately increasing and decreasing its intensity). The marked beam is transmitted to a distant mirror and the return beam passes through the apparatus that interrupts or modulates the outgoing beam and then to a detector. If the time required for transmission to the distant mirror and return is 1/2, 3/2, 5/2, . . . times the period of the interrupter (or modulator), then the amount that reaches the detector is small. It is usual to adjust either the path length or the period of the interrupter or modulator until the light registered by the detector is a minimum. In the earlier experiments, a mechanical chopper was used as interrupter, and the eye was the detector. Later experimenters used electronic modulators and photoelectric detectors.

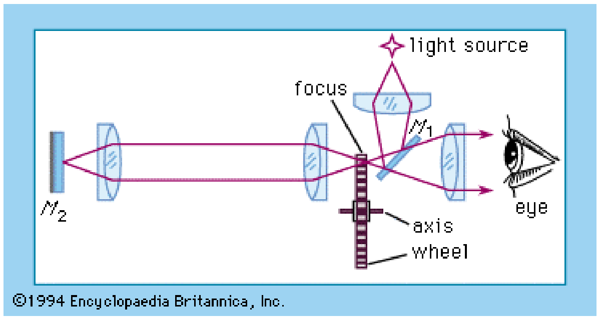

Figure 6: Fizeau's method for measuring the velocity of light.

The apparatus used by **Fizeau** in 1849 is shown in Figure 6, in which M1 is a partially reflecting mirror and M2 is a fully silvered mirror. As the speed of the wheel (which has 720 teeth) was increased from zero, it was found that the light was first eclipsed by a tooth when the speed was about 12.6 revolutions per second--i.e., when the time to make the round trip was 560 microseconds (0.00056 second), the length of the double path being 17.3 kilometres (about 10 miles). The chief error in the measurement lay in the difficulty of determining the exact speeds at which the light received by the eye at E was at a minimum. Essentially the same method was used by others between 1874 and 1903. The accuracy gradually improved, and it was shown that the velocity is between 299,000 and 301,000 kilometres per second.

In 1834 **Sir Charles Wheatstone** of England suggested a method incorporating a rotating mirror for interrupting the light that was later developed by **Arago** (1838) and **Foucault** (1850). It was considerably improved by **Michelson**, who made measurements from 1879 to 1935.

"Light: General considerations: VELOCITY OF LIGHT: Early terrestrial experiments." Britannica Online.
http://www.eb.com:180/cgi-bin/g?DocF=macro/5003/76/17.html

Michelson's measurements

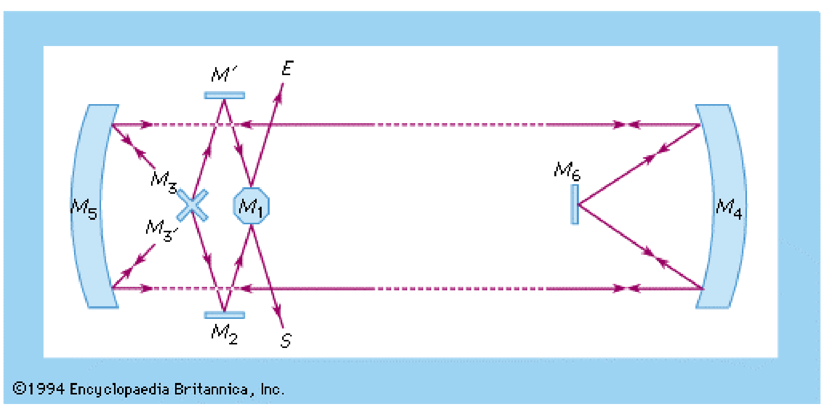

Figure 7: Michelson's Mount Wilson experiment, 1927.

Figure 7 shows the arrangement used in 1927. The mirror M3 is a little above the plane of the diagram, and M3' is a little below. Light from the source S passes to one face of the octagonal mirror M1 and then to M2, M3, and M4. From M4 it goes to the mirror M5 at a distance of about 35 kilometres (about 22 miles). It returns via M6, M4, M3', and M' to the octagon. An image of S is seen in an eyepiece at E. The octagonal mirror rotated at 528 revolutions per second. It turned through approximately one-eighth of a revolution during the transit of the light. If the rotation were exactly one-eighth of a revolution, the image would be undisplaced from the position it had when the mirrors were stationary. In some of **Michelson's** experiments, the speed of rotation was slowly changed until this condition was obtained. In others, the speed and distance were fixed, and a small displacement of the image was measured.

It is difficult to estimate the accuracy of **Michelson's** 1927 and 1935 experiments, and it is no longer important to do so in view of the more accurate measurements made since 1945. His most important contribution to the measurement of the velocity was the proof that the velocity agreed with Maxwell's prediction to better than one part in a thousand. This gave confidence to those working on applications of the electromagnetic theory.

"Light: General considerations: VELOCITY OF LIGHT: Michelson's measurements." Britannica Online.
http://www.eb.com:180/cgi-bin/g?DocF=macro/5003/76/18.html

The electro-optical shutter

This device, based on the **Kerr** effect (see below), makes it possible to modulate a beam of light at frequencies more than 10,000 times the highest frequency of interruption used by **Michelson** and obtain values in reasonably good agreement with each other and with **Michelson's** later work. This method was greatly improved by **E. Bergstrand** in Sweden, who reduced the random errors by a factor of more than 30 and obtained a value for the velocity of light of 299,793.1 kilometres per second.

Radio-frequency measurements

The velocity of electromagnetic waves of radio frequency in vacuum has been measured by several methods. An English physicist, **Louis Essen**, measured (1950) the resonance frequency of a cavity resonator (an electromagnetic device) whose dimensions were also determined with high accuracy. **Keith Davy** Froome, a physicist in England, measured (1952 and 1958) the wavelength in air, corresponding to a known frequency, using a microwave interferometer. The results of these and other measurements are in agreement with those of **Bergstrand** to within a few parts per million. The velocity of radio waves in vacuum is thus equal, within this accuracy, to the velocity of light. The velocity of gamma rays is also the same, within the much lower accuracy of this last measurement. Table 1 summarizes the measurements of the velocity constant (c) and shows that there is now satisfactory agreement between results obtained over a wide range of conditions.

Since the publication of the special theory of relativity (1905), the constant c has been recognized as one of the fundamental constants of modern physics. For this reason, attempts will undoubtedly be made to measure it with even greater precision. The use of lasers may help, but a major improvement will require the establishment of better standards of length and time than those now available.

"Light: General considerations: VELOCITY OF LIGHT: Radio-frequency measurements." Britannica Online. http://www.eb.com:180/cgi-bin/g?DocF=macro/5003/76/20.html

Velocity in material mediums

All measurements of the velocity of light involve interruption or modulation of a beam of light so as to form groups of waves and the velocity measured is the group velocity. The difference in magnitude between the wave velocity and the group velocity of light in air is only about one part in 50,000, but in most glasses and in some liquids it is much larger. **Michelson** obtained 1.758 for the ratio of the velocity in air to the velocity in carbon disulfide. The inverse ratio of their indices of refraction is 1.64 and the value calculated from this for the ratio of group velocities is 1.745 for wavelength 580 nanometres, close to **Michelson's** observations. **Bergstrand** found that the ratio of the velocity in vacuo to the velocity in a certain glass was 1.550 +/- 0.003. The refractive index of the glass was 1.519, but the ratio of c to the group velocity was 1.547. The experimental results thus agree with those calculated on the assumption that the measured velocity is the group velocity.

Table 1

Summary of Measurements of the velocity of light from terrestrial Experiments

(in kilometres per second)

Measured by Light Waves	**Year**	**Value**
Michelson	1927	299,796 + or - 4
Michelson, Pearson and Pease	1935	299,774 + or - 11
Value accepted in 1941	1941	299,773 + or - 3
Bergstrand	1951	299,793.1 + or - 0.2
Bergstrand (mean value)	1957	299,792.9 + or - 0.2
Value adopted by 17th General Congress on weights and Measures	1983	299,792.458 (defined)

Measured by Radio Waves	**Year**	**Value**
Essen (10,000 MHz)	1950	299,792.5 + or - 1
Froome (24,000 and 75,000 MHz)	1951-58	299,792.5 + or - 0.1
Value adopted by 12th General Assembly of the Radio-Scientific Union	1957	299,792.5 + or - 0.4

Electrical Measurements	**Year**	**Value**
Rosa and Dorsey (ratio of units)	1907	299,788 + or - 30
Mercier (Lecher wires)	1923	299,795 + or - 30

"Table 1: The Constant of the Velocity of Light" Britannica Online.
http://www.eb.com:180/cgi-bin/g?DocF=table/olight0001t1.html