Ruler Made Of Light

More Details

Light as a super-accurate measuring tool

Light, whether laser beam or candlelight, is nothing more than electromagnetic radiation that propagates through space as a wave. Each wavelength, i.e. the distance between two wave crests, corresponds to a very specific colour of light. The red laser light has a wavelength of about 600 nanometres (0.0006 mm); this means $5 \cdot 10^{14}$, i.e. 500,000,000,000,000 oscillations per second. The laser produces extremely uniform light waves, unlike a light bulb, which produces diffuse "light slush". With these fast and highly precise oscillations, the smallest changes can be measured: in the Michelson interferometer, a semi-transparent mirror splits the laser light into two exactly equal partial beams, which now travel separately, and are reflected by two mirrors before they finally meet again on the screen.

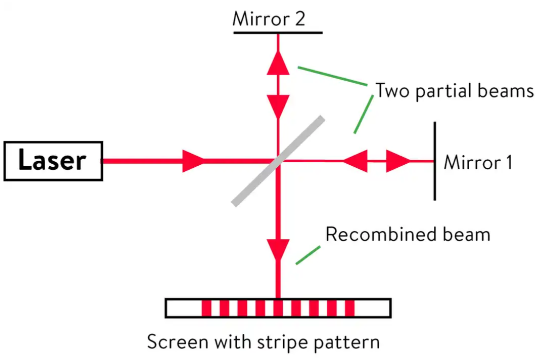

Abb. 1: Setup of the Michelson interferometer.

This is where it becomes visible what they encountered along the way: if, for example, the path of one beam was only half a wavelength (0.0003 mm) longer than that of the other, the crests and the troughs of the waves always meet when they merge, the beams interfere – their sum results in nothing but darkness, a black stripe on the screen. If the path of one beam is exactly one wavelength longer, the beams are amplified by interference – a bright strip is created on the screen.

From this stripe pattern, the distance that each partial beam has passed through can be precisely determined. The speed of the light can also be calculated from it: if one beam passes through air and the other through a vacuum, the second is a tiny bit faster – and alters the pattern.

Albert Abraham Michelson and the ether theory

How does light actually move? – This was the big question in physics in the late 19th century. It was known how sound waves move in air and how waves move in water, so it was thought that there must be a substance in which light waves move in a similar way: ether.

This ether was supposed to flood through the whole universe. The earth would fly through it on its way around the sun and therefore light rays on earth would be deflected by it very easily, like an aeroplane in a crosswind. The American physicist Albert Michelson, born in Poland in 1852, was particularly fascinated by this theory. From 1887, he tried to measure these deviations with his interferometer, but no matter how he looked at it, he could not find any deviation.

To his chagrin, Michelson practically refuted the ether theory, but only Einstein could theoretically explain how light propagates with the special theory of relativity in 1905.

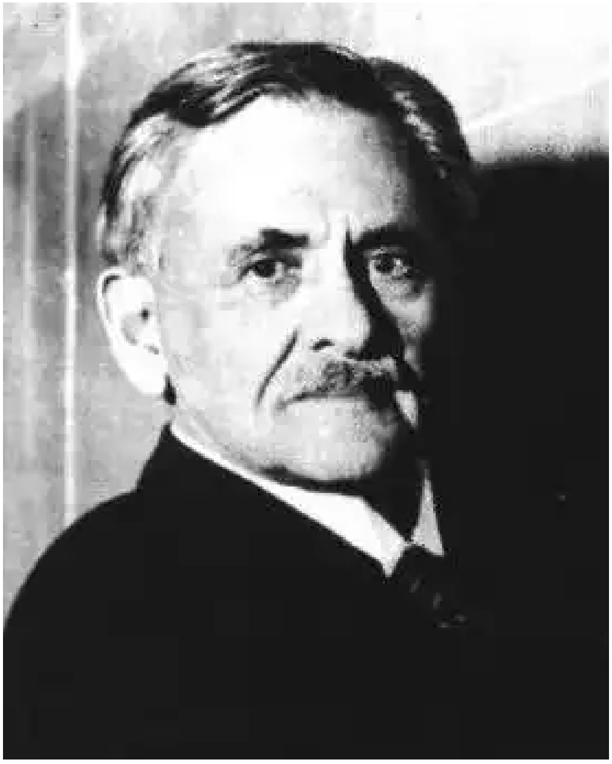

Fig. 1: Albert Abraham Michelson (1852-1931).

Gravity and space – was Einstein right?

According to Einstein's theory of relativity, changes in gravity (they occur, for example, when stars explode or orbit each other quickly) propagate as waves at the speed of light. These gravitational waves deform space-time and shake the whole earth, including us. Sounds strange – and is also difficult to measure, because the deformations are not greater than the diameter of an atomic nucleus! The Michelson interferometer is the first choice if you want to measure the tiniest changes.

For this purpose, the LIGO (Laser Interferometer Gravitational-Wave Observatory) was built. It consists of two huge interferometers at Hanford and Livingston in the USA. The instruments and techniques used there were partly developed in another huge interferometer, the

GEO 600, which is buried in a field near Hannover (Fig. 3). The greatest challenge in the measurements lies in the elaborate process of filtering out disturbing vibrations, such as the surf of the North Sea or the traffic in Hanover, from the measured data.

The scientists had to wait for a long time, but on the 14th of September 2015, the time had finally come: With both LIGO interferometers, a gravitational wave was detected for the first time! 1.3 billion light-years away, two black holes of 29 and 36 solar masses had collided, emitting very strong gravitational waves. Prior to this, they had been orbiting each other in a binary star system. It was very important that the signal was measured at both of LIGO's interferometers, allowing scientists to rule out disturbances from other vibrations in the nearby environment. With the first detection of a gravitational wave, the scientists were able to prove Einstein's theory of space-time. For this, Rainer Weiss, Barry Barish and Kip Thorne received the Nobel Prize in Physics in 2017.

Fig. 3: GEO 600 near Hannover from a bird's eye view. Clearly visible: the two 600 m long arms for the partial beams of the interferometer. The rest of the interferometer, the laser and the measuring station, is inside the red-rimmed building.