Interference – it's importance not only in surveying
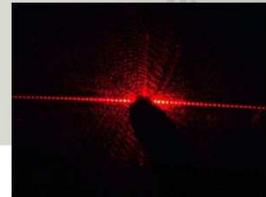
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INTRODUCTION

INTERFERENCE - the phenomenon of the a new, spatial pattern of the wave formation as a result of overlapping (superposition) of two or more waves. Usually refers to the interaction of waves that are correlated because they come from the same source or because they have the same or nearly the same frequency. Interference of waves consistent (coherent) gives a spatially constant wave amplitude distribution.

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During the superposition of the light coming from two sources other than lasers, or even from different positions of the same source, we do not observe interference. To induce it, the waves must be coherent, i.e. their phase difference can not depend on time. Such light waves from normal (not laser) sources are obtained by splitting the light coming from a single source into two or more beams. The radiation in each of them comes from the same atoms of the source and, due to their common origin, these beams are coherent. To split the light into coherent beams, the phenomenon of reflection or refraction of light may be used.
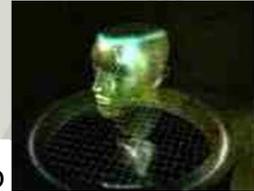
Utilisation of the interference phenomenon, examples

- measuring the distance from the source to the wave detector – interferometric laser rangefinders, gravimeters; measuring displacements and shape of objects,
- holography – spatial imaging technique by wave reconstruction method,
- noise reduction by means of a system generating sound waves in antiphase to the noise produced by a device,
- in telecommunications – division of the so-called communication network cell in order to facilitate independent signal transfer (UMTS technology).
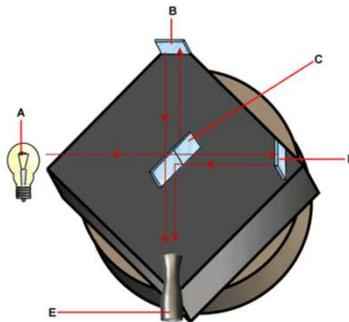
Albert Abraham Michelson

- born in 1852 at Strzelno in Kuyavia (Poland),
- lived in the USA since 1855,
- in the years 1889-1929 Professor of American universities: Case School of Applied Science in Cleveland, Clark University in Worchester, University of Chicago,
- member of the National Academy of Sciences in Washington,
- The Nobel Prize in 1907 for the construction of high-precision optical instruments (including the so-called Michelson interferometer) and measurements with their use,
- the second American Nobel Prize winner, and the first one in the field of science

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Michelson interferometer – scheme

A - light source,
C - translucent plate splitting a wave into beams,
B, D - mirrors reflecting light waves,
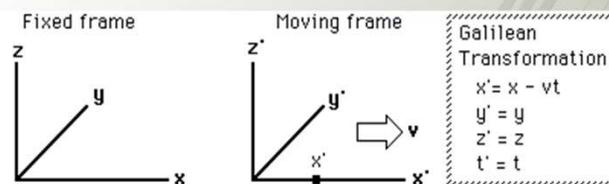E - telescope for reading interference pattern

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The most important Michelson's invention, which undoubtedly was the interferometer, enabled its inventor to carry out very accurate measurements of **the speed of light**, as well as other measurements in the field of metrology. In **1887,** Michelson and Edward Morley (American physicist and chemist born in 1838) conducted an experiment proving that **the speed of light did not depend on the motion of the Earth**. This experiment, showing no effect of rotational and orbit movement of the Earth on the speed of light, was of major importance for the later development of Einstein's special theory of relativity. Michelson experiment was supposed to confirm the existence of a hypothetical **aether,** the light carrier. A negative test result became an experimental basis for the theory of relativity.

THE HISTORY OF MEASURING THE SPEED OF LIGHT

Fixed frame   Moving frame

$$Galilean\ Transformation$$
$$x' = x - vt$$
$$y' = y$$
$$z' = z$$
$$t' = t$$

The primed frame moves with velocity v in the x direction with respect to the fixed reference frame.
The reference frames coincide at t=t'=0.
The point x' is moving with the primed frame.
The Galilean transformation gives the coordinates of the point as measured from the fixed frame in terms of its location in the moving reference frame. **The Galilean transformation is the common sense relationship which agrees with our everyday experience.**

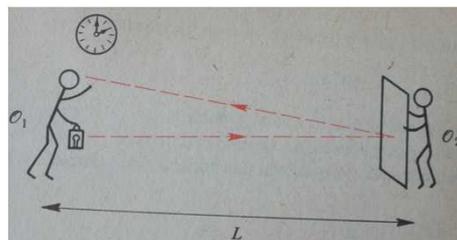Galilean transformation imaging for the velocity vector

Michelson and Morley's test results revealed the imperfection of classical mechanics. Galilean transformation failed in the case of Maxwell equations describing electromagnetic waves. According to the calculations based on Newtonian mechanics, the speed of light should depend on the motion of the observer relative to the hypothetical aether, in which electromagnetic waves were to propagate. It turned out, however, that contrary to the predictions of classical physics, the light travels at the same speed, regardless of the reference system. Initially, many physicists believed that such small divergences between the measurement results and the expectations of the mechanics may be eliminated thanks to e.g. more accurate measurements. Few assumed that the newly discovered shortcomings of the classical theory may lead to the formulation of new, more fundamental laws of nature. For Einstein, these inconsistencies in classical physics gave rise to a new theory.

In the **first half of the seventeenth century**, **Galileo** conducted the first experimental attempts to verify whether the speed of light is finite.

$$c = \frac{2L}{t}$$

t - time, after which the observer O_1 notices the light signal sent by him and reflected in a mirror held by the observer O_2
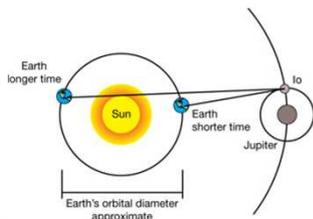
Members of the Italian Academy of Experiments (Accademia del Cimento), which was contemporary of Galileo, tried to conduct his experiment to measure the speed of light, but today it is clear that the experiment could not produce the intended result due to the inevitable experimental outliers, response time errors, etc., too large in relation to the speed of light.
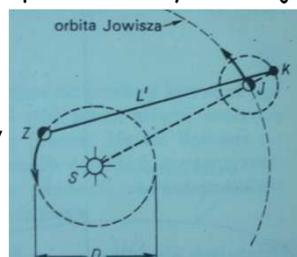
However, Galileo's merit was **the idea of measuring the speed of light** (the wave travelling back and forth), which was and still is used in numerous experiments.

Ole Roemer, a Danish astronomer, was the first to measure the speed of light in 1676, based on fluctuations in orbital cycle around Jupiter of one of its satellites, Io moon. Orbital period is determined from the observations of eclipses of Io by Jupiter. Roemer noted that as the distance between the Earth and Jupiter increased in its orbital motion, the moments of eclipses were delayed, and he concluded therefrom that this resulted from the time needed for the light to cover the Earth's orbit around the Sun.

Although the speed of light calculated in those conditions (214 000 km/s) deviated significantly from the currently adopted one, an important conclusion of the experiment was its finiteness, contrary to the belief represented by the majority of contemporary physicists.

The Sun (S), the Earth (Z), Jupiter (J), Io (K) – relative positions

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The next two centuries saw measurements of the speed of light by various methods, which resulted in the values closer to the current value of *c*

$$c = 299\ 792\ 458 \pm 1,2 \text{ m/s}.$$

In those days, until the nineteenth century, it was assumed that, similarly to, for example, the sound waves, the light in order to propagate needs a medium called the aether, penetrating through everything and present everywhere, even in a vacuum.

The aether would have to have unusual properties:

1) high resilience due to the large value of *c*,
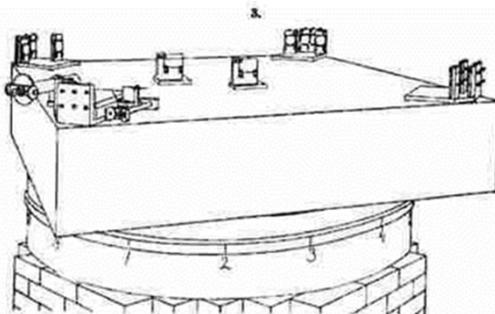2) excellent clarity and permeability, as the planets move without any noticeable resistance.
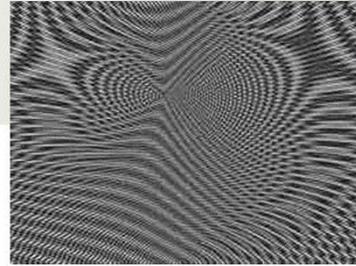

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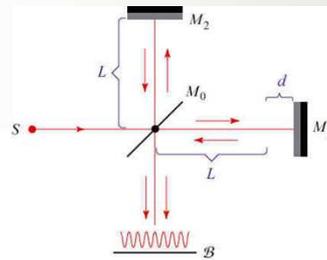
Each wave has a certain velocity in relation to the medium in which it propagates. Therefore, when measuring *c*, it is necessary to take into account the movement of the Earth relative to the aether.

Albert Michelson attempted to detect the motion of the Earth relative to the aether using an interferometer which he had constructed by himself.

Albert
Abraham
Michelson
interferometer

Scheme of the experiment using Michelson interferometer

Interference pattern

Michelson experiment was conducted as follows:

A beam of light comes from the source S onto a translucent plate M_0, where it is split into two beams travelling to the mirrors M_1, M_2. After being reflected, the waves pass through the plate again, and are directed to the telescope $\mathcal{B}$, in which light and dark fringes are observed - the result of interference of the beams. Interference pattern depends on the difference of beam optical paths, which may vary in sections $M_0M_1M_0$ and $M_0M_2M_0$, due to the mobility of the mirror M_1.

Due to the rotational and orbital motion of the Earth, the setting of the interferometer changes, relative to the stationary aether. Let the arm **M_0M_1** of the length **$L+d$** be directed along the Earth's velocity vector relative to the aether: $\vec{v}$, and the arm **M_0M_2** of the length **L** - perpendicular to $\vec{v}$. The time difference to be covered by the two beams can be calculated as follows:

$$t_1 = \frac{L+d}{c-v} + \frac{L+d}{c+v} = \frac{2(L+d)}{c \cdot \left(1 - v^2/c^2\right)} = \frac{2(L+d)}{c}\gamma^2 \tag{1}$$

$$t_2 = \frac{2L}{\sqrt{c^2 - v^2}} = \frac{2L}{c}\gamma \tag{2}$$

where:

$$\gamma = \frac{1}{\sqrt{1 - \left(v/c\right)^2}} \tag{3}$$

therefore:

$$\Delta t = t_1 - t_2 = \frac{2\gamma}{c}(\gamma L + \gamma d - L) \tag{4}$$

Having rotated the interferometer by 90 degrees, the mirrors M_1, M_2 shall swap roles. Performing similar calculations, we determine the time difference in this position:

$$\Delta t' = \frac{2\gamma}{c}(L + d - \gamma L) \qquad (5)$$

Thus, in the field of vision of the telescope, the interference pattern should change. It can be calculated by how much the interference fringes should move, knowing the Earth's orbital velocity v = 30 [km/s], the wavelength λ = $6 \cdot 10^{-7}$ [m] of the yellow light used in the experiment, and the distance between the plate and the mirrors, L = 1.2 [m]. It was calculated that this shift should be k = 0.04 fringes:

$$k = \frac{c \cdot (\Delta t - \Delta t')}{\lambda} \approx \frac{2L}{\lambda} \cdot \left(\frac{v}{c}\right)^2 \qquad (6)$$

when d = 0.

This value is very small, yet observable. However, the shift was negligible, less than 0.01 interference fringes.

Repetition of the experiment, over and over again, for many years and for different wavelengths, with increasing the distance to be covered by the light should result in a greater displacement of the interference pattern. However, it was consistently less than 0.01 interference fringes. The shift is proportional to the square of the ratio of the Earth's velocity relative to the aether, to the speed of light (6), and so a negative result of the Michelson-Morley experiment proved that the Earth's velocity relative to the aether is much smaller than its orbital speed. Subsequent use of lasers and masers (these are devices operating like lasers, but emitting radiation in a different frequency range) significantly improved the accuracy of calculations. The conclusion of the zero effect of the Earth's motion relative to the aether on the measured speed of light was confirmed. Thus, **the aether does not exist**, and c=const does not depend on the frequency of the wave, the direction of propagation in space, nor on the relative motion of the observer and the source.

USING INTERFERENCE IN SURVEYING INSTRUMENTS

- **absolute gravimeter** to measure the absolute value of the gravity - ballistic gravimeter determining gravity acceleration based on the free fall of a body in a vacuum; the use of a **laser interferometer** to determine the path of a falling body,
- **electromagnetic interferometric rangefinders** (mobile radio interferometer),
- **interferometric radars** used in remote sensing to create a digital terrain model, as well as in land subsidence monitoring on large areas,
- **laser interferometers** for remote control of industrial surface deformation.

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Thank you for your attention ☺