Measuring the velocity of light

Related topics

Refractive index, wavelength, frequency, phase, modulation, electric field constant, magnetic field constant.

Principle and task

The intensity of the light is modulated and the phase relationship of the transmitter and receiver signal compared. The velocity of light is calculated from the relationship between the changes in the phase and the light path.

Equipment

Light velocity measuring app.	11224.93	1
Screened cable, BNC, l 1500 mm	07542.12	2
Oscilloscope, 20 MHz, 2 channels	11454.93	1
Block, synthetic resin	06870.00	1

Problems

1. To determine the velocity of light in air.
2. To determine the velocity of light in water and synthetic resin and to calculate the refractive indices.

Set-up and procedure

The deviating mirror and the lenses are set up in such a way that the incident and emergent light rays are parallel to the base plate (Fig. 1) and a maximum signal reaches the receiving diode (detailed directions can be found in the operating instructions).

The modulation frequency of 50.1 MHz (quartz stabilised) is reduced, to the approximately 50 kHz so that the transmitter and receiver signals can be displayed on the oscilloscope.

1. First of all, the mirror is placed as close to the operating unit as possible (zero point on the scale). A Lissajous figure appears on the oscilloscope (XY-operation) and is transformed into a straight line using the ‘phase’ knob on the operating unit. The mirror is then slid along the graduated scale until the phase has changed by π, i.e. until a straight line sloping in the opposite direction is obtained.

The mirror displacement Δx is measured; the measurement should be repeated several times.

2. The water-filled tube or the synthetic resin block is placed in the path of the ray so that its end faces are perpendicular to the optic axis; the mirror is placed directly behind them (top of Fig. 3). A supporting block can be used with the resin block so that the light passes through it in both directions.

A straight line is obtained on the oscilloscope again with the ‘phase’ knob. The medium is then taken out of the path of the

Fig. 1: Experimental set-up for measuring the velocity of light in synthetic resin.

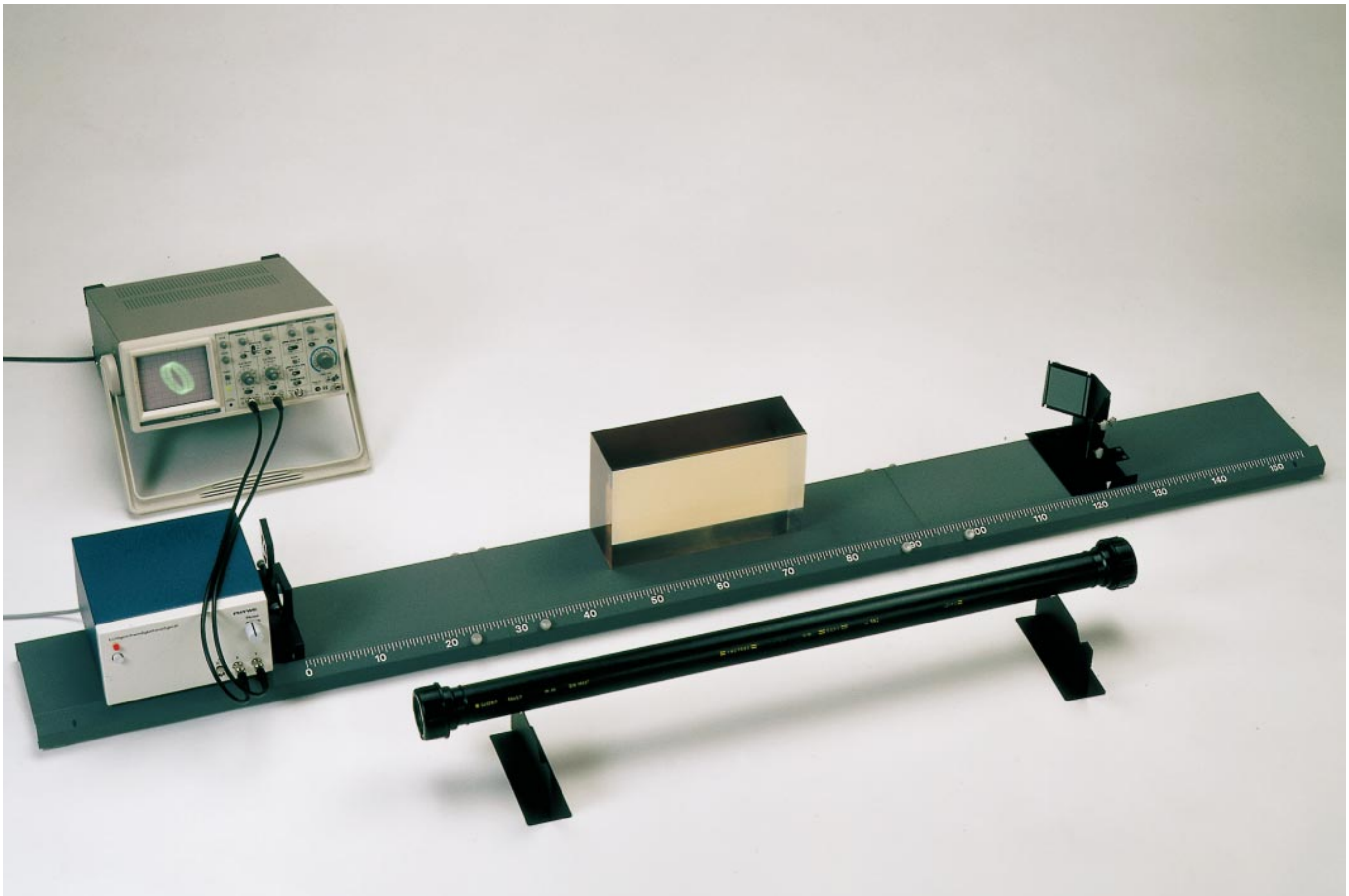
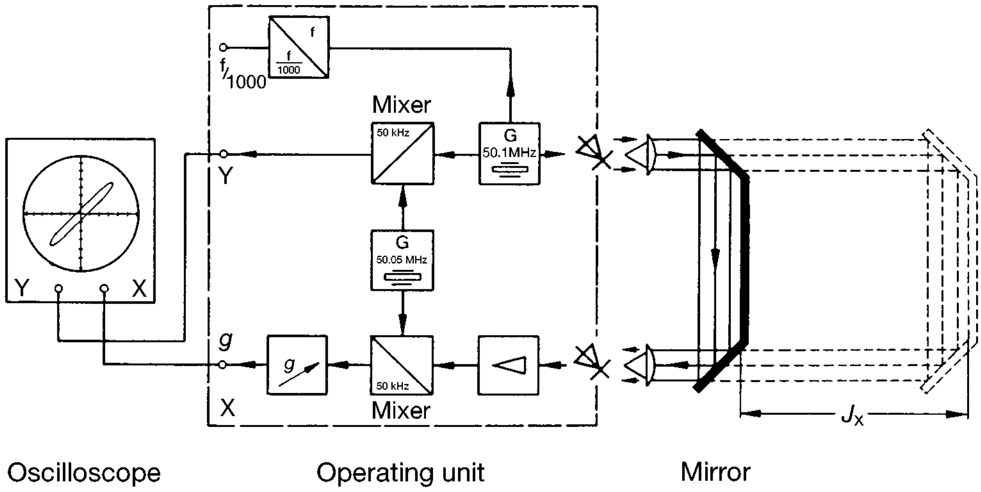


Fig. 2: Diagram of the experimental set-up for measuring the velocity of light in air.



rays and the mirror moved until the Lissajous figure agains shows the same phase difference.

The mirror displacement Δx is measured several times.

Theory and evaluation

The velocity of light is obtained as follows from Maxwell's equations:

$$c = \frac{1}{\qquad} \tag{1}$$

where $\epsilon_0 = 8.854 \cdot 10^{-12}\ \frac{\mathrm{F}}{\mathrm{m}}$

is the electric field constant,

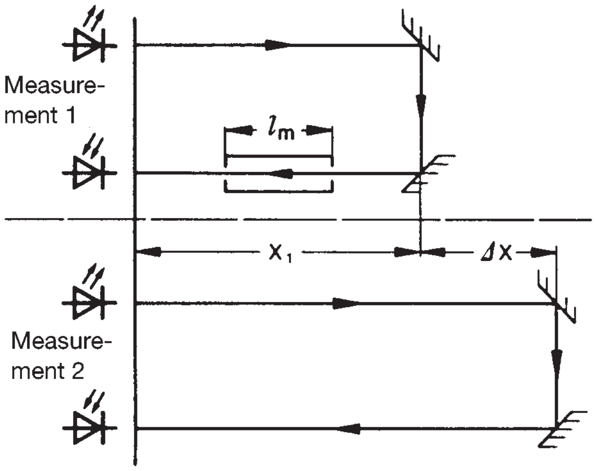


Fig. 3: Measuring the velocity of light in other media.

$$\mu_0 = 1.257 \cdot 10^{-6}\ \frac{\mathrm{H}}{\mathrm{m}}$$

is the magnetic field constant,

ϵ the relative permittivity of the medium and μ its permeability.

The refractive index of a medium is the quotient of the light velocity in a vacuum and in the medium.

$$n = \sqrt{\epsilon \cdot \mu} \tag{2}$$

$\mu = 1$ for most transpartent substances.

Relative permittivity and refractive index are dependent of frequency (dispersion) because of the natural vibration of atoms and molecules. Red light (LED) is used in the experiment. The phase relationship between transmitter and receiver signal is represented by a Lissajous figure on the oscilloscope. If it is a straight line, the phase difference is 0 in the case of a positive slope and π in the case of a negative one.

1. In order to measure the velocity of light in air, the light path is extended by

$$\Delta l = 2 \cdot \Delta x$$

(Fig. 2), to produce a phase change of π: i.e. to travel this distance the light requires a time

$$\Delta t = \frac{1}{2f}$$

where f = 50.1 MHz, the modulation frequency.

The velocity of light in air is thus expressed by

$$c_L = \frac{\Delta l}{\Delta t} = 4f \cdot \Delta x \tag{3}$$

The average of 10 measurements was:

$$c_L = (2.98 \pm 0.01) \cdot 10^8 \ \frac{m}{s}$$

Value taken from literature:

$$c_L = 2.998 \cdot 10^8 \ \frac{m}{s}$$

2. The velocity of light in water or synthetic resin, c_M, is measured by comparing it with the velocity of light in air c_L (Fig. 3).

In the first measurement (with the medium), the light travels a distance l_1 in time t_1.

$$l_1 = 2x_1$$

$$t_1 = \frac{1}{c_L}(l_1 - l_m) + \frac{1}{c_M} l_m$$

In the second measurement (no medium), the light travels a distance

$$l_2 = l_1 + 2\Delta x$$

in time

$$t_1 = \frac{1}{c_L}(l_1 + 2\Delta x)$$

The phase relationship between transmitter and receiver signal is the same in both cases, so that

$$t_1 = t_2 + \frac{k}{f}; \ k = 0, 1, 2\ldots$$

We thus obtain the refractive index

$$n = \frac{c_L}{c_M} = \frac{2 \cdot \Delta x}{l_m} + 1 + \frac{k \cdot c_L}{f \cdot l_m} \qquad (4)$$

In water, the distance measured l_m = 1 m, so that the term

$$k \cdot \frac{c_L}{f \cdot l_m} \simeq 6 \cdot k$$

In synthetic resin, for a distance m of 30 cm, the term

$$k \cdot \frac{c_L}{f \cdot l_m} \simeq 20 \cdot k$$

From the expected magnitude for the refractive index we can deduce that

$$k = 0, \text{ therefore } t_1 = t_2 \qquad (5)$$

The measurements in water give

$$n_{H_2O} = 1.335 \pm 0.002$$

$$c_{H_2O} = (2.23 \pm 0.01) \cdot 10^8 \ \frac{m}{s}$$

Values from literature:

$$n_{H_2O} = 1.333$$

$$c_{H_2O} = 2.248 \cdot 10^8 \ \frac{m}{s}$$

For the synthetic resin block we obtain the following:

$$n_{\substack{\text{synthetic}\\ \text{resin}}} = 1.597 \pm 0.003$$

$$c_{\substack{\text{synthetic}\\ \text{resin}}} = (1.87 \pm 0.01) \cdot 10^8 \ \frac{m}{s}$$