Measuring the velocity of light (Item No.: P2210101)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
Physik	Hochschule	Licht und Optik	Ausbreitung von Licht	Measuring the velocity of light

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	10 Minutes	10 Minutes	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Refractive index, Wavelength, Frequency, Phase, Modulation, Heterodyne technique, Electric field con-stant, Magnetic field constant

Overview

Short description

Related topics

Refractive index, wavelength, frequency, phase, modulation, heterodyne technique, electric field con-stant, magnetic field constant.

Principle

The intensity of a laser diode is modulated with a high frequency and the beam is reflected, after travelling some distance, back into the apparatus. The phase of the received signal is compared to the one transmitted. The velocity of light is then calculated from the measured phase difference, the modulation frequency and the length of the light path.

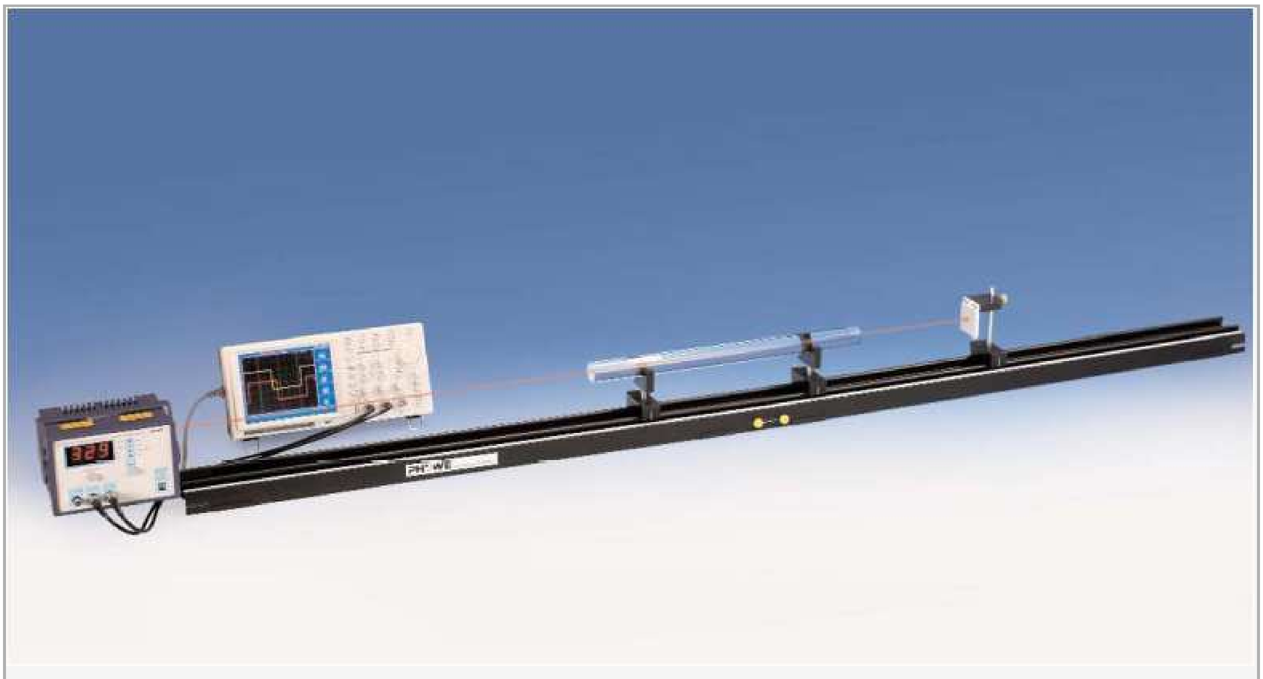

Fig. 1: Set-up of experiment

Equipment

Position	Material	Order nr.	Quantity
1	Speed of Light Meter Set	11226-88	1
2	30 MHz digital storage oscilloscope with colour display,2 x BNC cables l =75 cm incl.	11462-99	1

Tasks

1. Determine the velocity of light in air.
2. Determine the velocity of light in water and calculate the refractive index.
3. Determine the velocity of light in acrylic glass and calculate the refractive index.

Set-up and procedure

The light velocity measuring apparatus and the mir-ror are set up in such a way that the laser beam hits the mirror no matter where along the base the mirror is placed (more detailed directions can be found in the operating instructions of the Speed of Light meter). First the socket $f_{emmit}/1000$ is connected to the oscilloscope and the modulation frequency f_{emmit} (divided by 1000) is determined. The reason for introducing the fixed factor 1/1000 into the hardware be-tween the modulator and the socket, is that a relatively simple oscilloscope can be used for the task.
After determination of the modulation frequency, the two other sockets ($f_{emmit} - f_{sync}$ and $f_{rec} - f_{sync}$) are connected to the two input sockets of the oscilloscope. The frequencies of the emitted and the received signal are also reduced to 50 KHz while conserving their phase relation so that they can be dis-played on this type of oscilloscope.

Task 1: The velocity of light in air
At the start the mirror is placed close to the operating unit, the mode " $\Delta\phi$ " is selected and the button "Calibration" is pressed to have two coinciding signals visible on the oscilloscope. (See Fig. 2)
The mirror is then slid along the graduated scale. For at least 10 different displacements Δx (> 100 cm) the time difference Δt is calculated from the readings performed on the oscilloscope. (See Fig. 3).

Task 2: The Velocity of light in water and Task 3: The Velocity of light in acrylic glass
The water-filled tube or the acrylic glass rod is placed so that the laser beam runs through them, the mirror is placed directly behind. The "Calibration" button is pressed. Again the oscilloscope will show a graph similar to Fig. 2. The tube/rod is then taken out of the path of the rays, the two signals will not coincide any longer. Now the mirror is moved a distance Δx until the two signals on the oscilloscope coincide again as before with the medium inserted. The mirror displacement Δx is measured several times.

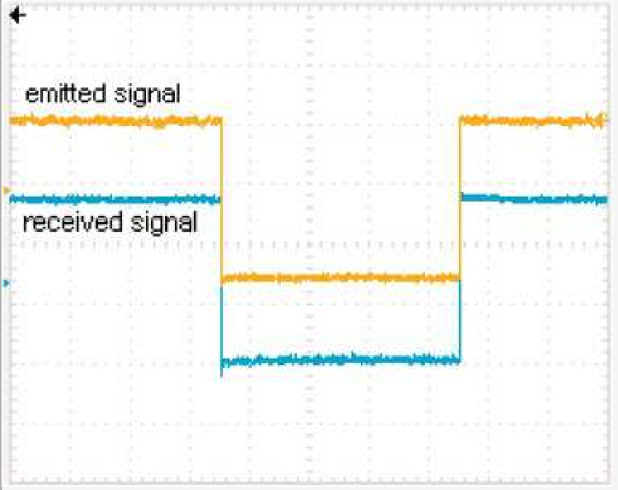

Fig. 2. Oscilloscope signal after "Calibration".

Theory and evaluation

Although light travels very fast, its velocity is finite. Since 1676 when Romer estimated the velocity of light using spatial scales that included the distances to the moons of Jupiter much technical development took place. These days we can comfortably measure the speed of light on a table top. In the SI system, the metre is defined as the distance light travels in vacuum in 1/299792458 of a second. The effect of this definition is to fix the speed of light in vacuum at exactly
299 792 458 m/s.

Velocity of light in air:
To obtain the velocity of light, one has calculate $\Delta t/\Delta s$. Where Δt is the time the light takes to travel the distance Δs . The distance Δs is $2 \cdot \Delta x$ because the additional stretch is twice the mirror displacement since the laser beam has to travel to the mirror and back again.
Table 1 gives an example of a measurement:

Δx in mm	Δs in mm	Δt in ns	$c = \Delta s/\Delta t$ in $(m/s \cdot 10^8)$
1000	2000	6.6	3.03
1100	2200	7.3	3.01
1200	2400	7.9	3.03
1300	2600	8.6	3.02
1350	2700	9.0	3.00
1400	2800	9.3	3.01
1450	2900	9.6	3.02
1500	3000	9.9	3.03
1550	3100	10.3	3.01
1600	3200	10.6	3.02
			av. val.: 3.018

Velocity of light in water/acrylic glass
The velocity of light in water or acrylic glass, c_m , is measured by comparing it with the velocity of light in air c_a (Fig. 4). In the first measurement (with the medium), the light travels a distance l_1 in time $t_1 (l_1 = 2x1)$.
In the second measurement (no medium), the light travels a distance $l_2 = l_1 + 2\Delta x$ in the same time.

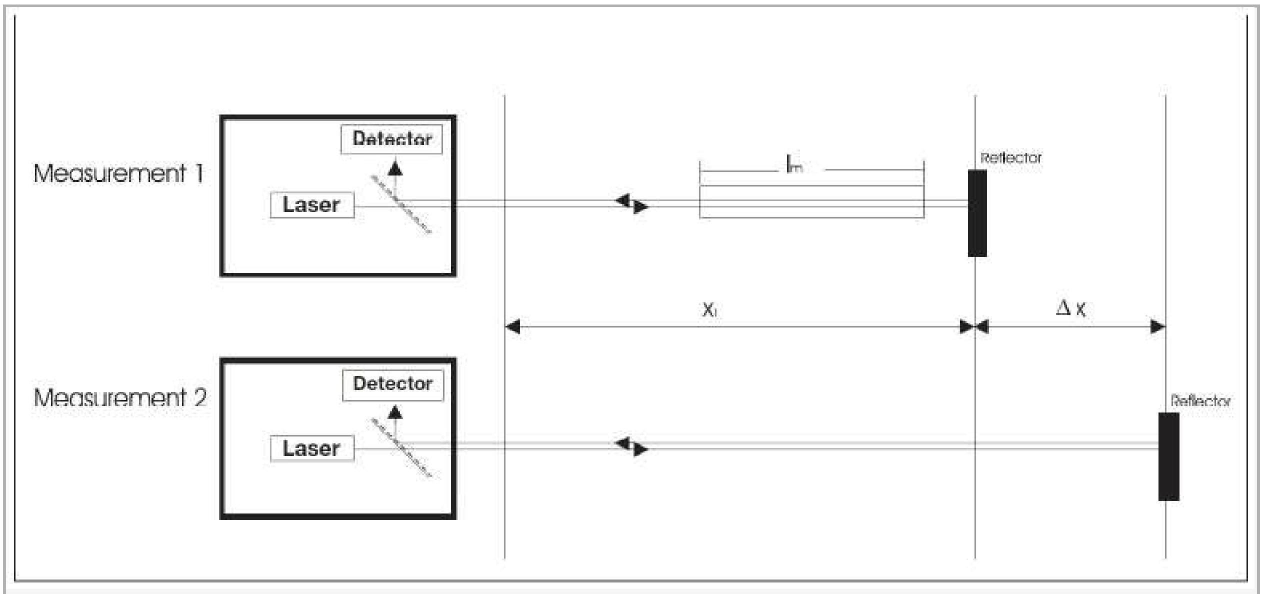

Fig. 3: Principle for measuring the velocity of light in a medium

This means that light takes the same time to travel the distance $2\Delta x + 2l_m$ in air as it takes to travel the distance $2l_m$ in the medium.
From this and the definition of the refractive index, it follows directly, that

$$n_m = \frac{(2\Delta x + 2l_m)}{2l_m} = \frac{(\Delta x + l_m)}{l_m}$$

and

$$c_m = \frac{c_a}{n_m}$$

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For the water-filled tube, with $l_m = 500mm$ as the length of the water column and a measured Δx of 170 mm, this leads to:

$n = 1.34$, (literature value: $n_{water} = 1.33$)

$c_{water} = 2.23 \cdot 10^8 m/s$

For the acrylic glass cylinder, with $l_m = 490mm$ and $\Delta x = 240mm$:

$n = 1.49$, (literature values are in the range from: $n = 1.48$ to $n = 1.52$)

$c_{acrylicglass} = 2.01 \cdot 10^8 m/s$

Note

The evaluation as described here relies completely on the measurements performed with the oscilloscope. No use is made of the displayed values on the velocity of light apparatus.

The reasons for this are mainly didactical ones: The students learn to operate an oscilloscope and they will trust the results more if they measured them themselves this way instead of taking the reading off an apparatus that is made just for this specific measurement. Nevertheless, in many settings (e.g. demonstration in class) it might be quite helpful to use the features built into the apparatus that are described in the manual.