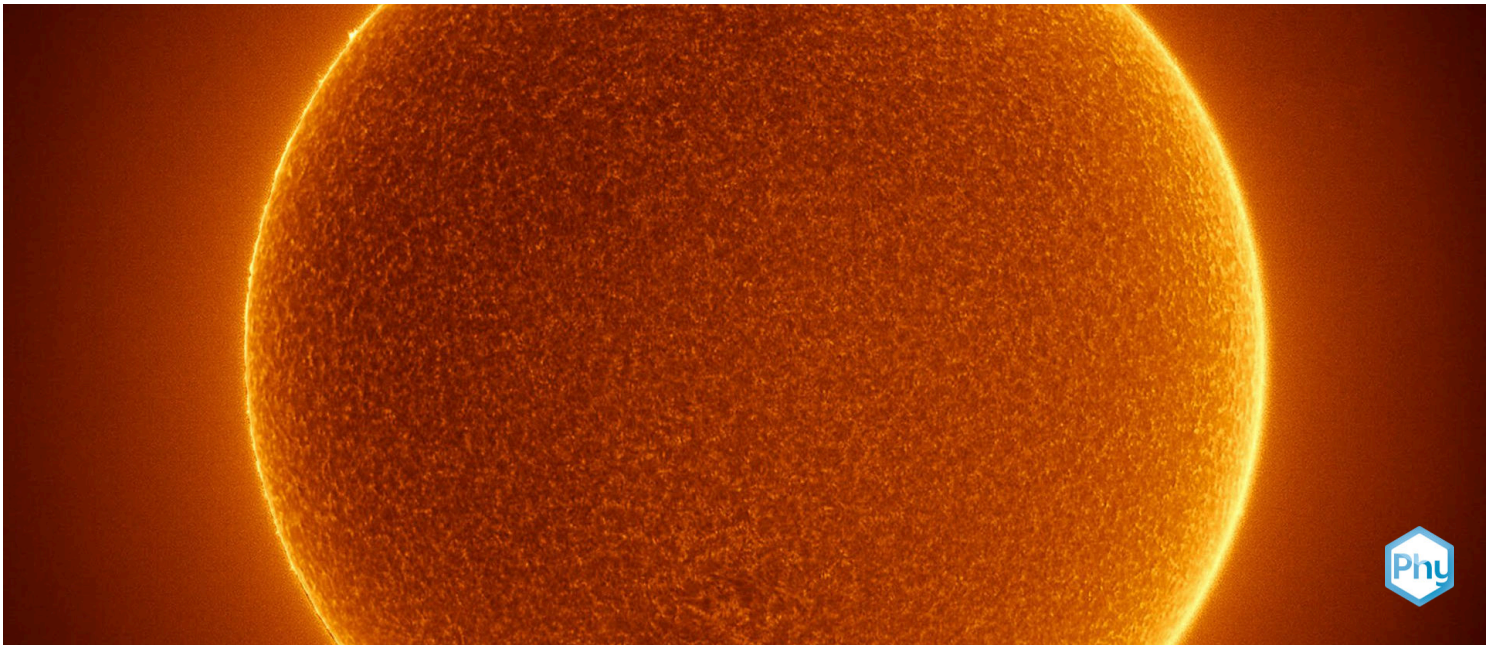
Measuring the velocity of light



Physics > Light & Optics > Dispersion of light

Physics > Light & Optics > Diffraction & interference

Difficulty level	Group size	Preparation time	Execution time
hard	2	10 minutes	10 minutes

This content can also be found online at:

http://localhost:1337/c/5f086042b07bda00037309c0

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General information

Application

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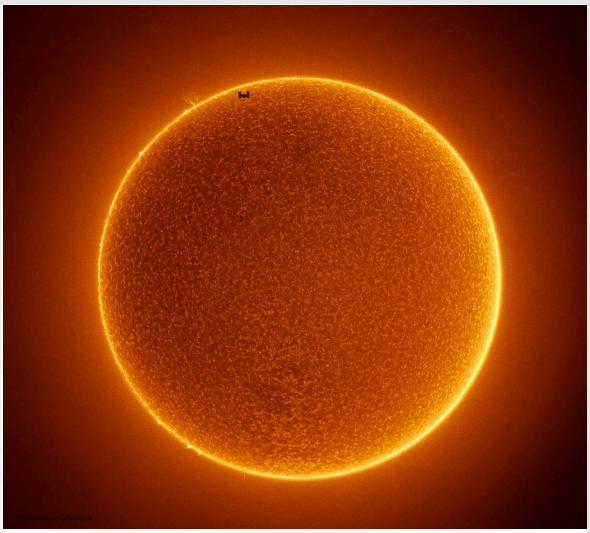

Image of the sun

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.

In astronomy, the velocity of light has been used to measure the distances in the solar system. For example, it takes light 8 minutes and 17 seconds to travel from the Earth to the Sun, which the distance can be defined as 149,597,870 km.

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Other information (1/2)

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Prior knowledge

Light is an oscillating electromagnetic wave that could travel from one medium to another medium. If it reaches the interface between the two media, some part of the incident beam is reflected and some is transmitted, which known as refraction.

Scientific 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.

Other information (2/2)

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Learning objective

To study the influences of refractive index on the velocity of light, by allowing the laser beam to propagate in transparent media, e.g. air, glass and water.

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.

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Safety instructions

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- The common rules of safe experimentation in scientific education apply in this experiment.
- The generally applicable rules for handling lasers according to the ANSI and IEC Laser Classification must be considered.

Theory

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In the SI system, the metre is defined as the distance light travels in vacuum in 1/299 792 458 of a second. The effect of this definition is to fix the speed of light in vacuum at exactly 299 792 458 m/s and it is denoted by c. To obtain the speed of light, one has to calculate $\Delta s / \Delta t$, where Δt is the time which the light takes to travel the distance Δs.

During the propagation of light in other medium, such as glass or water, the light travels slower than in vacuum. The ratio between c and the speed v at which the light travels in a medium is called the refractive index n of the medium ($n = c / v$). Increasing refractive index corresponds to decreasing speed of light in the medium. When light leaves the medium and returns to a vacuum, its velocity returns to the usual speed of light.

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Equipment

Position	Material	Item No.	Quantity
1	Speed of Light Meter Set	11226-88	1
2	Screened cable, BNC, l = 750 mm	07542-11	2
3	Digital storage oscilloscope, 20 MHz, 2 channels, 100 MS/s	EAK-P-1335	1

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Setup and procedure

Setup (1/2)

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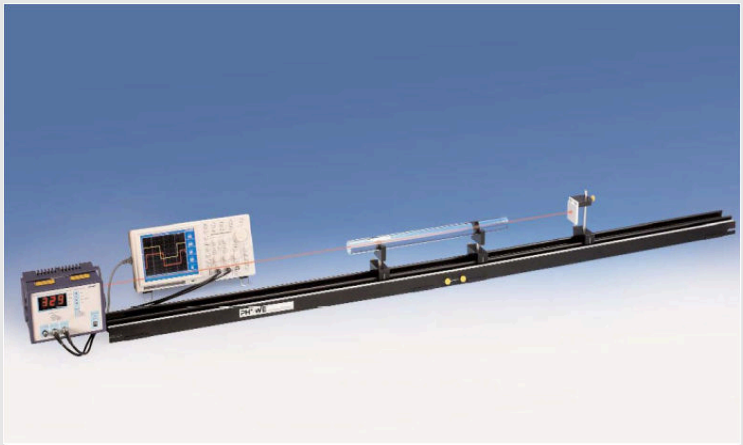

Set-up of experiment

The experiment set-up is shown in the Figure on the left. The light velocity measuring apparatus and the mirror 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).

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Setup (2/2)

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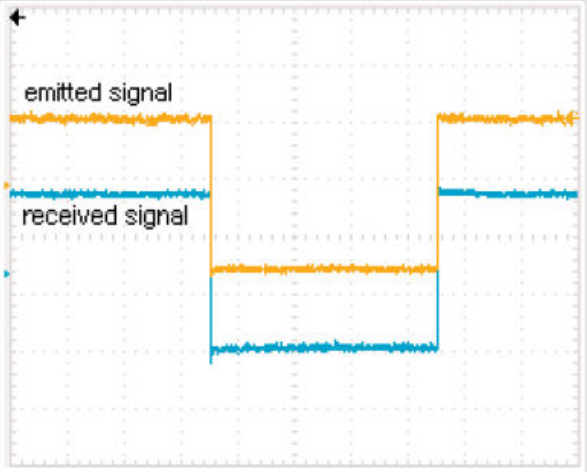
1. The socket ($f_{emmit}/1000$) is connected to the oscilloscope and the modulation frequency femmit (divided by 1000) is determined.
2. The two other sockets ($f_{emmit} - f_{sync}$ and $f_{rec} - f_{sync}$) are connected to the two input sockets of the oscilloscope. The frequencies of the emitted and the received signal are also reduced to 50 KHz while conserving their phase relation so that they can be displayed on this type of oscilloscope.
3. The "Calibration" is pressed for every new measurement.



Oscilloscope signal after "Calibration"

Procedure (1/2)

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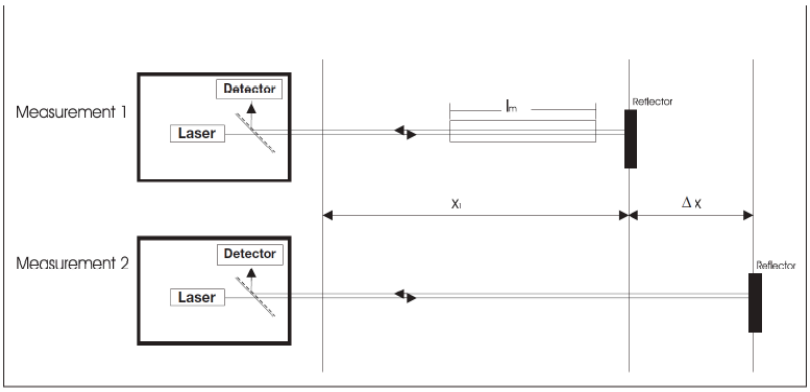

Oscilloscope signal after "Calibration"

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.

The mirror is then slid along the graduated scale. For at least 10 different displacements Δx (> 1000 mm) the time difference Δt is calculated from the readings performed on the oscilloscope.

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Procedure (2/2)

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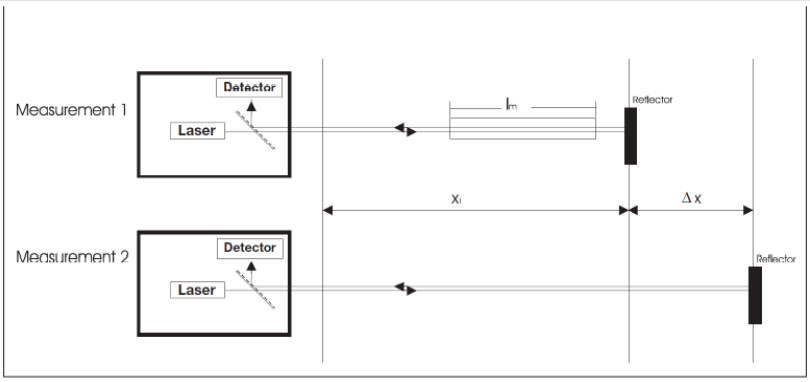

Oscilloscope signal after "Calibration"

Task 2+3: The velocity of light in water and 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 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.

Evaluation (1/4)

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Δx in min	Δs in mm	Δt in ns	c in (m/s $\cdot 10^8$)
1000	2000	6.6	3.03
1100	2200	7.3	3.01
1200	2400	7.9	3.03

Example: Measured values

Velocity of light in air:
To obtain the velocity of light, one has calculate $\Delta s/\Delta t$. 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.

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Evaluation (2/4)

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Velocity of light in water/acrylic glass

Velocity of light in water or acrylic glass, *v* is measured by comparing it with the velocity of light in air *c*. In the first measurement (with the medium), the light travels a distance l_1 in time t_1 ($l_1 = 2x_1$).

In the second measurement (no medium), the light travels a distance $l_2 = l_1 + 2\Delta x$ in the same time. 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

$n_m = (2\Delta x + 2l_m) / 2l_m = (\Delta x + l_m) / l_m$

Evaluation (3/4)

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Following the measurement of the speed of light, the refractive index of a medium can be determined.

During the propagation of the light in the air, the speed of light is approximately _____. The measured velocity of light in water is approximately _____ and in acrylic glass is _____, which given the refractive index of the water and the acrylic glass _____ and _____ respectively.

1.33

2x10^8 m/s

3x10^8 m/s

1.5

2.26x10^8 m/s

Check

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Evaluation (4/4)

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Which of the following statements are true regarding the velocity of light

- [ ] The ratio of the velocity of light in vacuum to that in a denser medium is defined as refractive index
- [ ] The refractive index varies with wavelength
- [ ] The frequency of the wave is affected by the refractive index
- [ ] The velocity of light increases in the denser media

Check

Slide	Score / Total
Slide 15: Determination of the velocity of light	0/5
Slide 16: Refractive index	0/2

Total Score 0 / 7

Show solutions Retry

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