

Measuring the speed of light

1 Purpose and comments

Determine the speed of light by sending a laser beam through various mediums. Do not place your eyes in the beam path! Also, Switch the laser on at least 10 minutes before starting the experiment.

2 Theory

2.1 Speed of light

The following scenario is about two light sources inserted in a tube that is evacuated. One is fixed on the surface of the earth and the other is moving in a perpendicular direction from the surface of the earth. Also, we have a fixed satellite above the light sources which will measure the velocity of the incoming light. The satellite records the velocity of both light sources and it determines the velocity of both sources to be the same. This is called the constancy of the speed of light. This only refers to the speed of light in vacuum. The speed of light in different mediums is what you will be determining in this experiment. Note, as of January 25, 2016 the current measurement of the speed of light in vacuum is approximately 299,792,458 m/s. (Nothing in life is certain)

You will obtain the velocity of light in air. To measure it you need to take into account Δt and Δs . Keep in mind what Δs should be. The velocity of light in water, acrylic glass, and polydimethylsiloxane is determined by comparing it with the velocity you obtain in air. c_a (Fig. 1)

In measurement 1 the light passes through a medium with a distance of l_1 with a duration of t_1 . In measurement 2 there is no medium, so the light travels at a distance of $l_2 = l_1 + 2\Delta x$ with the same time. This implies light will take the same duration to travel a distance $2\Delta x + 2l_m$ in air as to travel a distance of $2l_m$ in a medium. With that in mind and the definition of index of refraction then,

$$n_m = \frac{(2\Delta x + 2l_m)}{2l_m} = \frac{(\Delta x + l_m)}{l_m} \quad (1)$$

and

$$c_m = \frac{c_a}{n_m} \quad (2)$$

You will need to determine the index of refraction of the different mediums that you will be using. Note, keep in mind the water temperature.

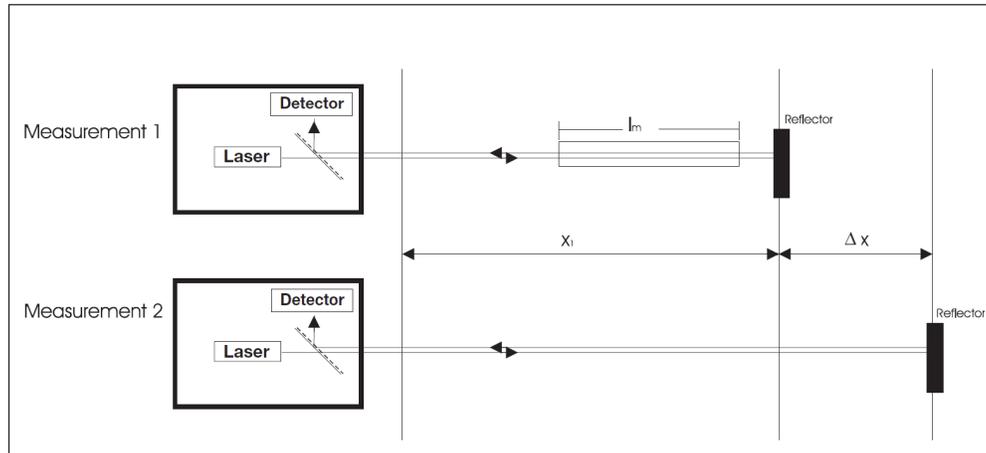


Figure 1: Determining the speed of light in water, acrylic glass, glycerin, etc.

3 Tasks and Equipment used

In this experiment you will determine the velocity of light in air, water, acrylic glass, glycerin and calculate the refractive index of the various mediums.

Miscellaneous items used 2-Screened cable, BNC, $l=750$ mm

Hardware 2 tubes labeled for the different mediums, Track, 2 U-Shaped brackets to hold the mediums.

Sensor Speed of light meter.

Measuring device Digital Oscilloscope 30 MHz

Other measuring devices 1-meter stick, thermometer, small ruler

4 Setup and how the speed of light meter works

SAFETY PRECAUTIONS



Laser radiation
Do not look into the beam
Laser Class 2

4.1 Description

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 section below). First the socket $f_{emit}/1000$ is connected to the oscilloscope and the modulation frequency f_{emit} (divided by 1000) is determined. The reason for introducing the fixed factor 1/1000 into the hardware between 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 ($f_{emit}-f_{sync}$ and $f_{rec}-f_{sync}$) are connected to the two input channels 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.

4.1.1 Purpose of the meter

The Speed of light meter serves to determine the speed of visible (red) light in air or in transparent liquid or solid media. The light source is a laser diode, the light intensity of which is modulated by a high frequency AC voltage of approximately 50MHz; so that the light beam exhibits time markers. After the light beam has travelled a certain distance, a retro-reflector directs back onto a photodiode. Here it generates an alternating voltage of the same frequency but one that is displaced in phase against the original signal in dependence on the length of the light path. All of the quantities required for the calculation of the speed of light are shown in the display. When various transparent media water, oil, synthetic resin, acrylic glass are brought into the light path, then the change in the speed of light caused by the particular material can be measured. Once the speed of light is known, the same instrument can be used to carry out the distance measurements.

4.1.2 Mode button on the meter

The Mode button toggles through the five different instrument modes, or rather the display of them. The particular mode that is active is shown by the LED that lights up red:

- (a) OFF - This is the initial mode. It is active as soon as voltage is applied to the instrument. The laser is switched off, the digital display shows OFF.
- (b) (f_{emit}) - The modulation frequency of the emitted laser light is displayed.
- (c) $\Delta\phi$ - In this mode, the phase displacement between the signal emitted and that received is displayed in degrees. The resolution is 1 degree, the value range from 0 to 359 degrees.
- (d) $\Delta t * 1000$ - The transit time of the signal can be directly calculated from the phase displacement and the modulation frequency and be shown here. As the phase displacement is measured by a heterodyne procedure at 1/1000 of the modulation frequency, 1000 times the transit time is to be shown here, so that the impression is not given that measurement is made directly of times in the ns range.
- (e) Δx - This mode is suitable for differential distance measurements. Here, the literature value of the speed of light is used internally to calculate the changed distance from

the retro-reflector Δx from the difference in transit times Δt . In accordance with the modulation frequency of 50MHz and the measurement procedure, Δx can only be unambiguous in the range from 0 to 2.99m. The resolution of the display is 1cm, the maximum tolerance is 5%.

4.1.3 Calibration button

When you press the Calibration button it sets the $\Delta\phi$, $\Delta t * 1000$ and Δx starting points for all the measurement. They are set to zero when the laser beam is reflected back to the instrument. The position of the mirror at this point in time is set to the zero point of measurement. The function of this button is in principle comparable to that of a tare button of a digital balance. The setting of the phase difference between the signal emitted and the signal received acts immediately on the signals at the BNC sockets and can also be well measured through an oscilloscope. This procedure must be carried out once after switching the instrument on for measurements to be able to be carried out. When the instrument receives the reflected laser beam, CAL blinks in the digital display, in as much as this had not been previously carried out.

4.1.4 Modulation frequency BNC socket

The modulation frequency of the laser light is led to an output reduced by a factor of 1,000, so that it can be measured with a simple oscilloscope. Together with the signals at the other two BNC sockets, this enables measurements to be made that are independent of the values in the digital display.

4.1.5 Signal emitted/Signal received BNC sockets

These two sockets can be used to evaluate the signal emitted and the signal received by means of a 2-channel oscilloscope. The phases of the two signals relative to each other are of particular importance here. In order not to have to use the fastest oscilloscope for this task, each of the signals are additively mixed with a synchronisation signal that is modulated to a 50kHz lower frequency than that of the laser light. This leads to signals in the 50kHz range whose phase positions relative to each other are the same as those of the original signals, but which can be comfortably evaluated with a normal oscilloscope.

5 Experimental procedures

5.1 Handling and setting up the beam

Switch the laser on at least 10 minutes before starting the experiment. This allows thermally-caused fluctuations of the beam which could affect the result of the measurements to be avoided. Position the Speed of light meter on the holder upon the optical bench. The magnetic film on the bottom of the instrument ensures a stable position but does not interfere with the horizontal alignment. Align the instrument and the retroreflector so that the beam strikes the reflector as central. Make sure the beam of the laser stays within the center of the optical track. Use a index card with a hole that is mounted on the holder to check the beam path.

5.2 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 Calibration button is pressed to have two coinciding signals visible on the oscilloscope. (See Fig. 2) Hint, to measure Δt on the scope you need to hit the Run/Stop button on the scope. After push the cursor button.

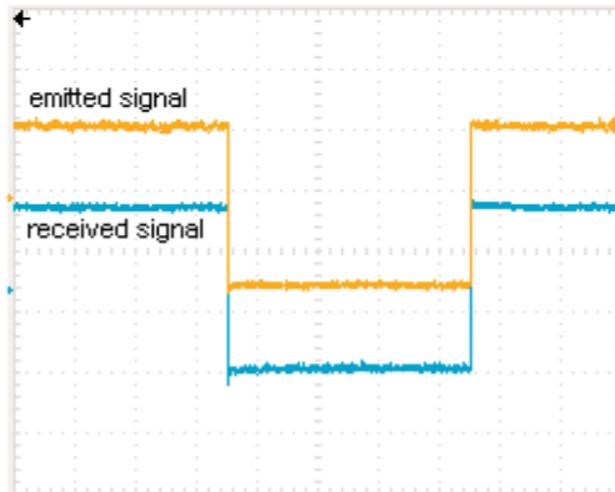


Figure 2: Oscilloscope signal after Calibration

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)

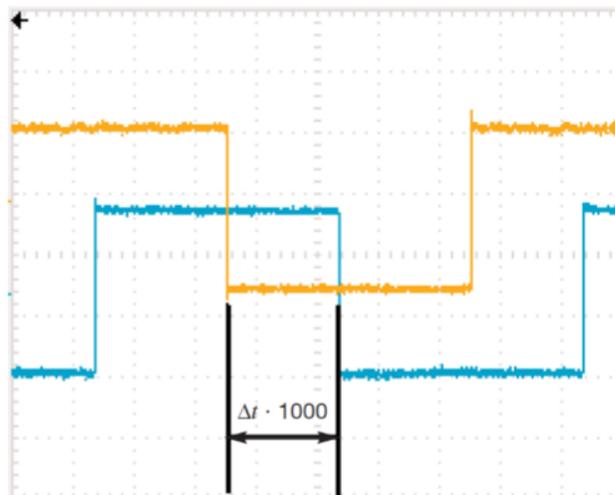


Figure 3: Measuring the time difference using the oscilloscope.

5.3 The Velocity of light in water, polydimethylsiloxane, and acrylic glass

The different media are placed so that the laser beam runs through the center of the mediums, 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 laser beams and 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. **Note: Do not open the tube with polydimethylsiloxane!**

5.3.1 Analysis and questions

1. What is the speed of light in air?
2. What is the speed of light in water and polydimethylsiloxane?
3. What is the speed of light in acrylic glass?
4. Why does the speed of light change in the different mediums?
5. Does the wavelength of the light change in different mediums? Explain.
6. How does the intensity of the light vary in the different materials? Explain.

5.4 Determining the material of an unknown rod

There is an unknown rod that is approximately 18 to 20 cm in length. You have to determine what the rod is made of by determining what is the index of refraction of the material. At this point you should know how to do this. The unknown rod can be

Material	Index of refraction
Sapphire	1.76
Potassium niobate	2.28
Pyrex	1.47
Cytop	1.34
Polycarbonate	1.60
Fused quartz	1.46

Choose carefully your grade depends on it.

5.4.1 Analysis and questions

1. What is the speed of light through the rod?
2. Rotate the rod and explain why does the phase displacement vary?

6 Finishing Up

Please return the bench to the condition in which you found it. Thank you.