

## *Determining the velocity of light using a laser motion sensor*

Experiment Objective: learn how to measure the time-of-flight of the light on its path to and back from the reflector, to determine the refractive indices of the some media.

### Tasks:

- to learn the method for light velocity determination by using a laser range finder;
- to determine the velocity of light in air;
- to determine the refractive indices of water and acrylic glass;
- determine the refractive index of the glass prism;

### Optical elements and apparatus:

- ✓ Laser motion sensor S (1);
- ✓ Sensor-CASSY (2);
- ✓ Cassy Lab PC (3);
- ✓ End buffer (4)
- ✓ metal ruler (5)
- ✓ Plate glass cell 50 x 50 x 50 mm (6);
- ✓ acrylic glass block (7)
- ✓ glass prism (8)

In a medium with a refractive index  $n$  not equal to one the phase velocity of the electromagnetic waves propagation  $c_m$  is determined according to:

$$c_m = \frac{c}{n}, \quad (1)$$

where  $c$  – the velocity of electromagnetic waves in vacuum (about  $3 \cdot 10^8$  meters per second).

By measuring the time that the light expends during the passage of a known distance in a substance, it is possible to determine the  $c_m$  and correspondingly to determine the refractive index of this medium.

Modern distance meters use a periodically modulated laser beam for the measurement. They determine the phase shift between the emitted and the reflected modulated laser beam and, with the modulation frequency being known, obtain the time-of-flight  $t$  of the light on its path to and back from the reflector. Therefore, the laser rangefinder measures the time and not the distance passed the beam. Distance is calculated from the known velocity of light in air. In this experiment, the laser motion sensor S (laser S) is used as a time-of-flight meter because it is also capable of outputting the time-of-flight  $t$  directly.

## Procedure:

### Exercise 1. Determining the velocity of light in air.

Assemble the installation which is shown in Fig. 1.

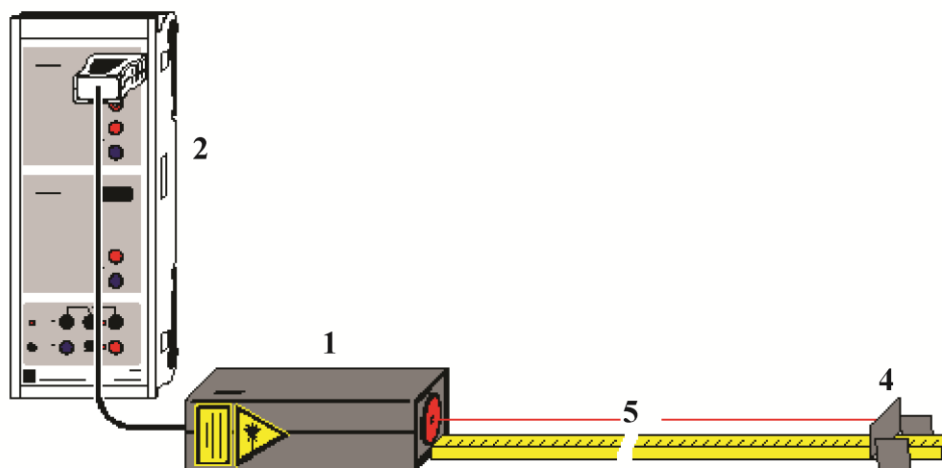


Fig.1. Experimental setup for determining the velocity of light.

### ***Safety note***

***Mind the safety notes in the instruction sheet of the laser motion sensor S:  
Never look into the direct or reflected laser beam. Do not look inside the sensor.***

Lay the laser motion sensor S (1) on the table with its broad side down, and connect it to the input of the CASSY (2). Connect the the CASSY (2) to PC by a USB cable. Put on the table a metal ruler (5) close to the laser motion sensor as shown on the Fig.1 (count starts from the sensor). Moving the end buffer (4) with a retroreflecting foil along the optical path make sure that the laser spot is completely falls in the reflective strips of paper up to a distance of 70 cm from the front of the laser sensor. If it is not, turn the laser motion sensor S and put it on the other side of the broad.

Set the end screen perpendicular to the laser beam above the ruler at a distance of 30 cm from the front of the laser sensor (distances are measured in a metal ruler) so that the laser beam impinges perpendicularly on the center of the foil. Before the measurement, allow the laser S to warm up for approximately 5 minutes in order that the zero shift becomes as small as possible.

Run the Cassy Lab 2 program on the PC. Click «Close» in a window with Cassy 2 interface. Load the settings to perform the work by command «File – Open» and select the directory D:/Experiment/. Select «All Files» to display all the files in the window that opens. Open the «Velocityc.labs» file. Re-close the window with Cassy 2. If the setup program (area 1 in Fig. 2) is not displayed, click «Show Settings» (2 in Fig. 2).

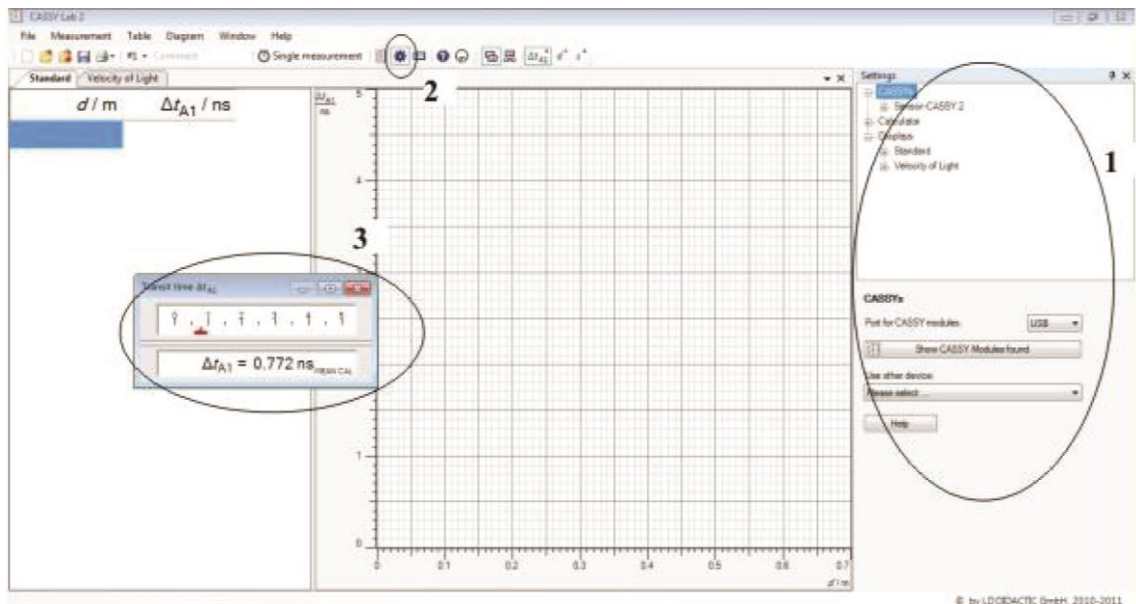


Fig.2. The Cassy Lab 2 program window after loading «Velocity» settings. 1 - the settings area of the program, 2 - «Show Settings» button, 3 - small window of measurements.

Further in the program settings consistently open the tabs Sensor-Cassy2 - Input A1 (Laser motion sensor S) - Transit time  $\Delta t_{A1}$ . At the bottom of the area 1 the settings window for measurement the laser pulse time-of-flight should be appear. Chose the time  $\Delta t_{A1}$  as the measurand. Its values are continuously displayed in a small window of measurements (see area 3 in Fig.2). Click the “→0←” button at the bottom of the  $\Delta t_{A1}$  settings window to define the zero of the time-of-flight. Now the values  $\Delta t_{A1}$  in the of measurements should be around 0.

In the left part of the operating window the tab Standard must be open. It will be filled during the measurement (see Fig. 2). Select the the first row of the left column ( $d/m$ ) by the left mouse button and enter the 0 value with the keyboard and press Enter. In the same way select the first line of the right column ( $\Delta t_{A1}/ns$ ) and press F9. You should see the value 0.000. Move aside the end screen from the laser sensor by 10 cm (40 cm on the ruler), then select the second line of the column ( $d/m$ ) by the left mouse button and enter the 0.1 meters value. Select the second line of the column ( $\Delta t_{A1}/ns$ ) and press F9. In a spreadsheet, you should see the measured value (remember that the sensor measures the total time-of-flight of the light on its path to and back from the reflector). Repeat the measurements at intervals of 10 cm to the screen position at the 70 cm by the ruler (vanishing the time value is not necessary). Continue to fill out a table recording the measured time-of-flight of the light on its path to and back from the reflector by pressing the button F9 each time.

After filling out of all cells go to the tab Velocity of Light, which by this time will contain the same table, but the columns will be swapped. In the right part of the working area on the x-axis is time in ns and axis y is distance in meters. Experimental data are shown by dots. To determine the velocity of light in air it is necessary to approximate the experimental data by a straight line. To do this, open a section Diagram of the programs upper line and select Fit Function, Best-fit

Straight Line. Hold down the left mouse button and put the cursor on the first point (0,0) then still holding the mouse button draw a line through the all the points (they should be colored in blue). Release the button at the end point and optimal straight line will appear automatically. Straight line settings are in the lower left corner of the window (When the Velocity of Light tab is open parameters will be calculated taking into account that the light go on its path to and back from the reflector so it is not necessary to normalize the value to 2).

Determine the velocity of light in air. Compare with a table value.

Exercise 2. The refractive indices of water and acrylic glass determination by a laser rangefinder.

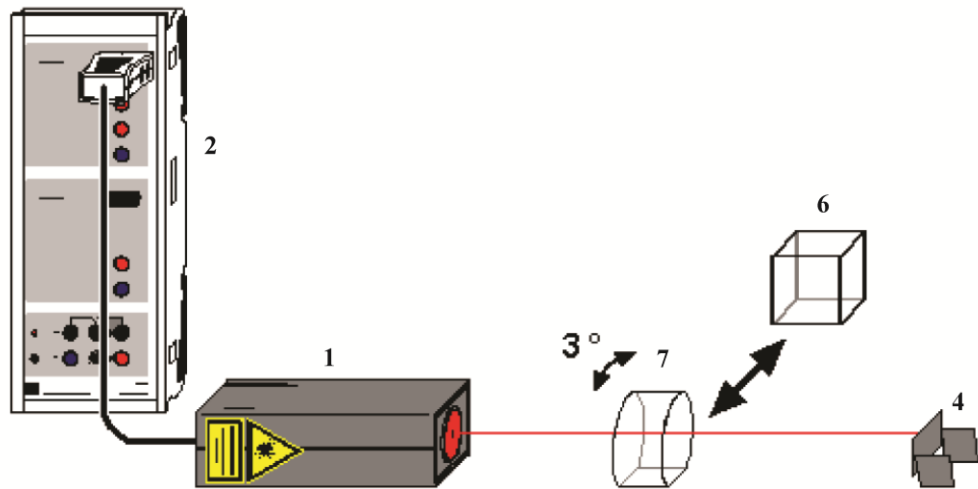


Fig.3. Experimental setup for determining the refractive indices of water and acrylic glass.

For this exercise you need to install the end screen on the table perpendicular to the laser beam at a distance of 50 cm from the front of the laser sensor. After that, a metal ruler can be removed from the table. Define the zero of the time-of-flight in the Cassy Lab 2 program (see Ex. 1). Hold the acrylic glass block (7) into the path of the beam such that the visible reflections of the laser beam from the glass surface are not reflected back to the laser (rotate the acrylic glass block by approximately 3°). Record the first measuring point  $\Delta t_1$  which is the difference between the time of the laser beam passage without the block and with the block. Measure the acrylic block length  $d$  with a ruler and determine the refractive index of the substance according to:

$$n = 1 + \frac{c}{2d} \Delta t. \quad (2)$$

Remove the acrylic glass block from the optical path. Hold the empty and dry plate glass cell (6) into the path of the beam such that the visible reflections of the laser beam from the glass surface are not reflected back to the laser (rotate the cell by approximately 3°). The increase of the length of the path resulting from this rotation is smaller than 1 % and can thus be neglected. Define the zero of the time-of-flight in Cassy Lab 2 program. Carefully fill the plate glass cell with water and record the measuring point  $\Delta t_2$ . Knowing the length of the glass cell edge

determine the refractive index of the water according to formula 2. Compare with a table value.

Exercise 3. Determination of the refractive indices of glass prism.

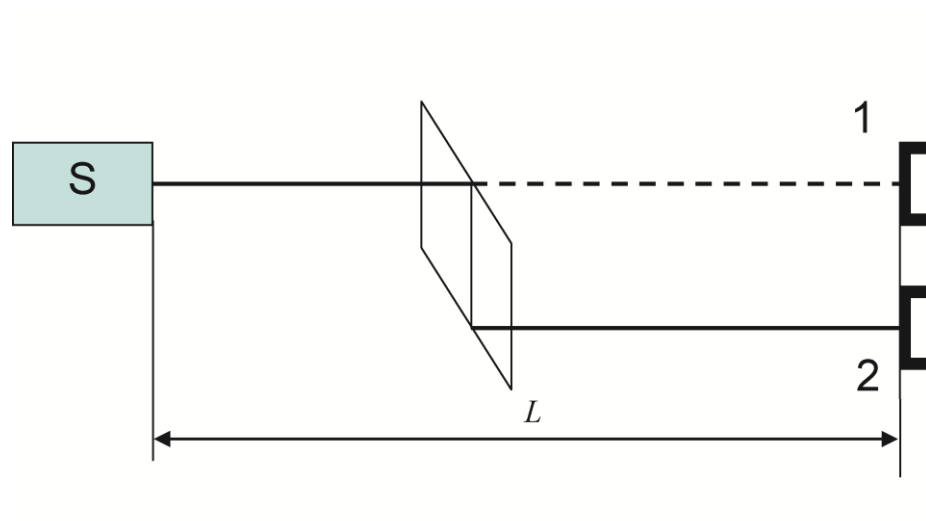


Fig.4. Experimental setup for determining the refractive indices of glass prism with the base angle  $45^\circ$ . S – laser motion sensor, 1 and 2 – end buffer position.

In this exercise is necessary to keep a constant distance between the laser sensor and the plane in which the front surface with the retroreflecting foil of the end buffer is situated (distance  $L$  in Fig.4). The experimental setup is the same as in the Exercise 2. Initially, there is no prism in the optical path. Buffer is situated at a distance of 50 cm from the front side of the laser sensor (position 1 in Fig.4). You can use the ruler keep the constant distance between the laser sensor and the plane of the buffer. Put it on the table close to the rear of the buffer. Define the zero of the time-of-flight in Cassy Lab 2 program. Hold the prism with the base angle  $45^\circ$  into the path of the laser beam (Fig. 4). The front prism face should be almost perpendicular to the laser beam (considering that the beam reflected from the front face of the prism, is not fall to the laser sensor hole). Carefully move the end buffer along the ruler so that the laser beam still impinges perpendicularly on the center of the foil (position 2 in Fig.4). Record the  $\Delta t$  time value.

Deduce a formula for the refractive indices of glass prism calculation (it is not equal to formula 2). Knowing the linear size of the prism determine the refractive index of it.