2OS7

Velocity of light measurement

Introduction

Determination of the velocity of light in air

Consider a setup as shown in Figure 1. The light beam, which emerges from the transmitter diode, hits the receiver diode (a photodiode) after a measurable path. On hitting the receiver diode, the light beam causes an alternating voltage with the same frequency as the transmitted signal but with a shifted phase. To allow for this phase difference to be displayed on the oscilloscope (as an ellipse known as the Lissajous figure), the modulation frequency $f = 50.00$ MHz of the transmitter diode is transformed within the operating unit to a frequency of about 50 kHz.

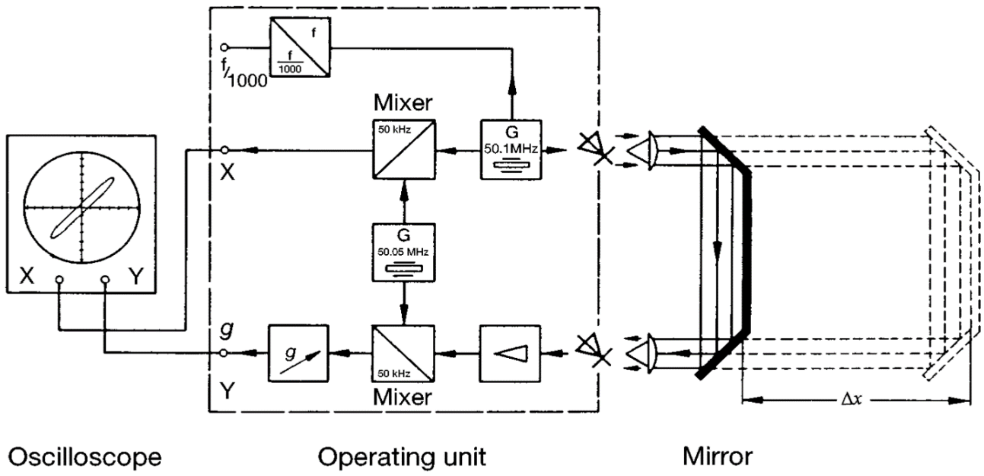

Figure 1 A schematic diagram of the experimental setup to determine the velocity of light in air.

The phase difference is 0 when the oscilloscope displays a positive slope straight line. Meanwhile, the phase difference is 180° ($= \pi$) when the oscilloscope displays a negative slope straight line.

In this experiment, you would move the mirror away from the operating unit, such that the straight line changes its slope from negative to positive. The additional length of the path that the light beam has to cover until it reaches the receiver diode is

$$\Delta l = 2 \times \Delta x \tag{1}$$

where Δx is the mirror displacement.

To cover the additional path Δl, the light beam needs the time

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

where $f = 50.00$ MHz is the modulation frequency of the transmitter diode.

Now, light velocity can be calculated.

Determination of the velocity of light in water and synthetic resin

In Figure 2, you can see a sketch of the experimental setup for this part of the experiment.

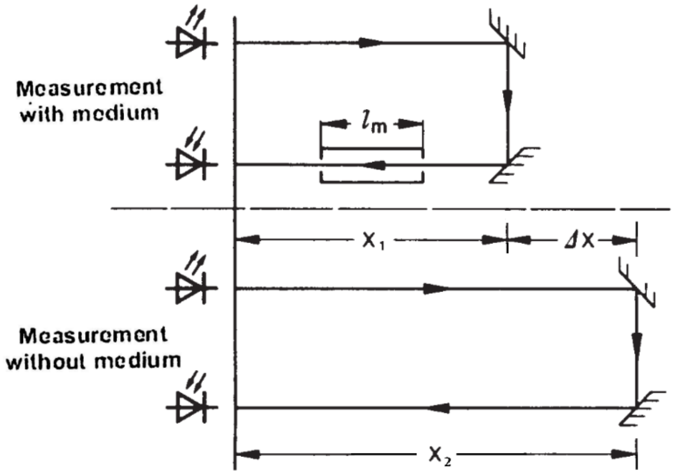

Figure 2 A schematic diagram of the experimental setup to determine the velocity of light in a medium.

In this part of the experiment, you obtain a straight line on the oscilloscope, which has the same slope at the mirror positions x_1 and x_2. This means that the phase difference is the same in both cases. Thus, the light beam covers the two different paths in the same time t.

The path that the light beam covered in the measurement with the medium is l. Therefore, the path of the light in the measurement without the medium is

$$l + 2 \times \Delta x \tag{3}$$

where

$$\Delta x = x_2 - x_1 \tag{4}$$

in equation (3).

For the two measurements, one gets the following equations for the time t:

Measurement with medium: $$t = \frac{l}{c_a} - \frac{l_m}{c_a} + \frac{l_m}{c_m} \tag{5}$$

Measurement without medium: $$t = \frac{l}{c_a} + \frac{2 \times \Delta x}{c_a} \tag{6}$$

where c_a is the velocity of light in air, l_m is the length of the light path through the medium and c_m is the velocity of light in the medium.

From the equations (5) and (6) one gets:

$$\frac{c_a}{c_m} = \frac{2 \times \Delta x}{l_m} + 1 \tag{7}$$

$$\Rightarrow c_m = \frac{c_a \times l_m}{2 \times \Delta x + l_m} \tag{8}$$

In this experiment, the length of the water-filled tube is $l_{\text{water}} = 1$ m and the length of the synthetic resin block is $l_{\text{synthetic resin}} = 30$ cm $= 0.3$ m.

Objectives and scope of the experiment

1. Determination of the velocity of light in air.
2. Determination of the velocity of light in water and synthetic resin.
3. Calculation of the refractive indices of water and synthetic resin.

Setup and preparation

Set up and prepare the experiment according to the following instructions and pictures:

1. Put the operating unit on the leftmost side of the base plate next to the scaling (Figure 3).

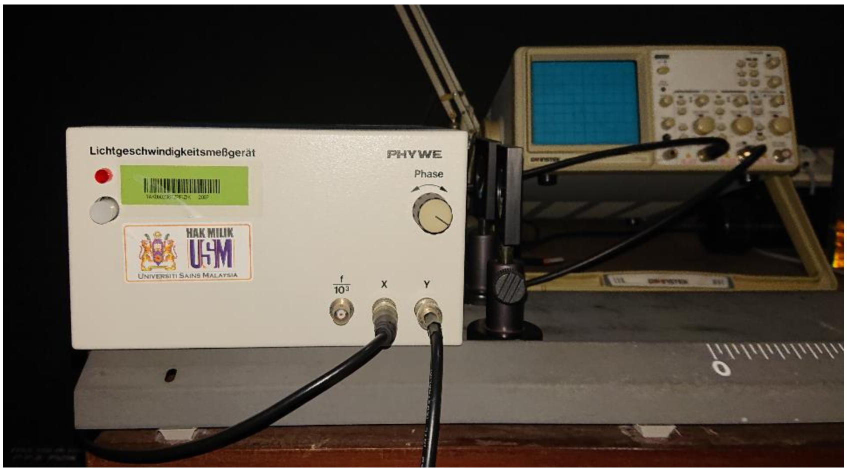

Figure 3 The operating unit on the left side of the base plate.

2. Connect the operating unit to the oscilloscope with the two screened cables as shown in Figure 4 and Figure 5 (connect the X- and Y-outputs of the operating unit to the respective X- and Y-inputs of the oscilloscope).

Figure 4 Screen cables connected to the operating unit.

Figure 5 Screened cables connected to the oscilloscope.

3. Switch on the operating unit and activate the X-Y-mode of the oscilloscope using the button shown in Figure 6. The bottom right of the oscilloscope monitor should then display "X-Y", indicating that the mode is currently in use (see Figure 7).

Figure 6 The X-Y-mode button.

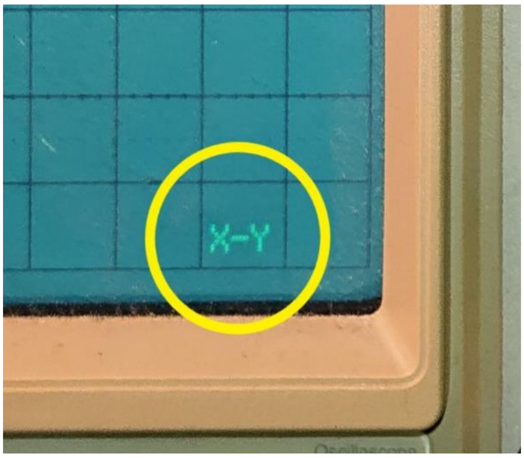

Figure 7 Confirmation that X-Y-mode activated.

4. Adjust the initial sensitivity of the X- and Y-channels, using the knobs shown in Figure 8, to 5 V/cm and 500 mV/cm respectively. The sensitivity currently in use is shown on the bottom left of the oscilloscope monitor (Figure 9).

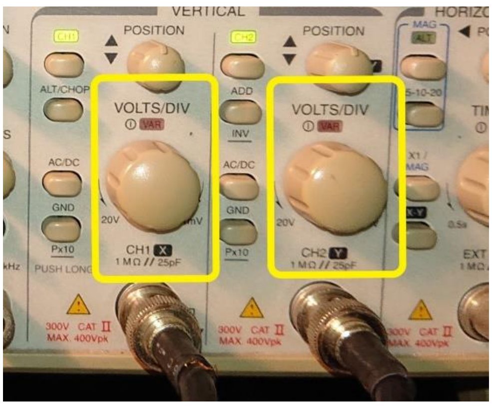

Figure 8 Sensitivity adjustment knobs.

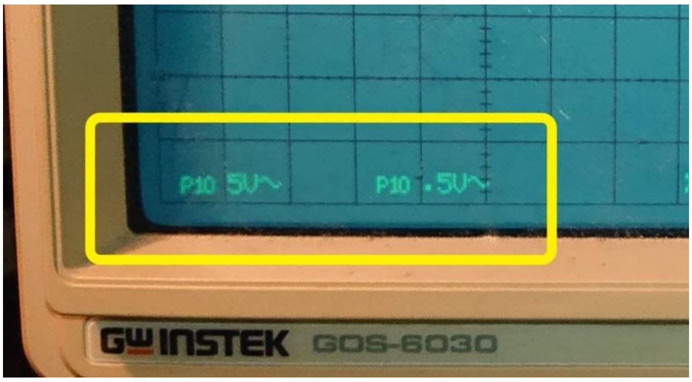

Figure 9 Sensitivity of the oscilloscope.

Note that you would need to adjust the sensitivity accordingly throughout the experiment to get the best result.

5. Make sure that the INTEN rotary switch is turned to the left (Figure 10) (use this rotary switch during the experiment to change the brightness of the display).

Figure 10 The INTEN rotary switch.

6. All other rotary switches and buttons should be left in the standard (or neutral) positions.

Figure 11 Rotary switches and buttons on the oscilloscope.

Adjustment of the condense lens and the mirror

7. Put a condense lens in front of the transmitter diode of the operating unit, about 3.5 to 4.0 cm away (Figure 12). Make sure that the plane side of the lens faces the operating unit.

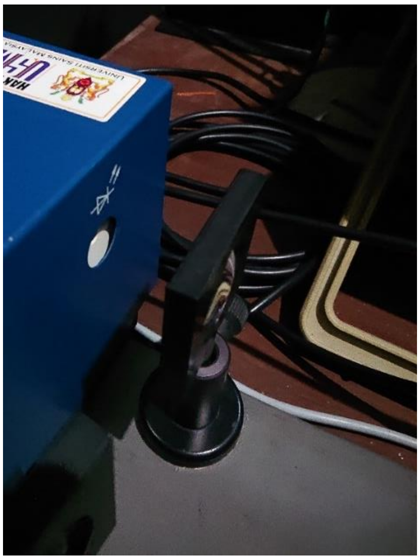

Figure 12 A condense lens in front of the transmitter diode.

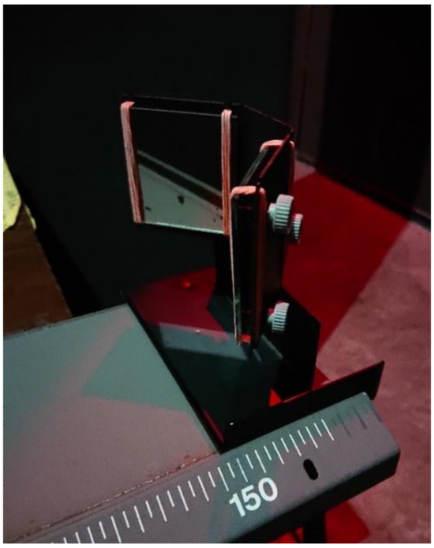

Figure 13 Mirror at the right end of the base plate.

8. Place the mirror onto the right end of the base plate (Figure 13).
9. Switch on the operating unit (and the oscilloscope if you haven't done so).
10. Use a piece of white paper to follow the emerging light beam and hold it in front of the mirror.
11. Adjust the lens vertically, horizontally and in its height until you can see a sharp image of the diode on the piece of paper (Figure 14)

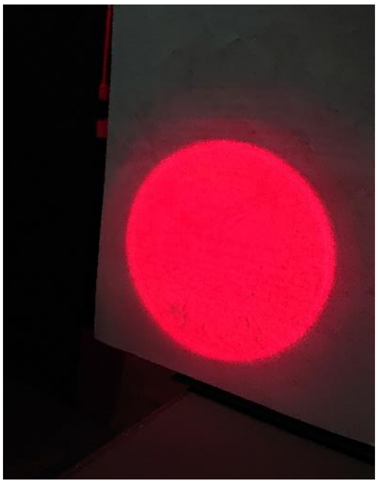

Figure 14 A sharp image of the diode.

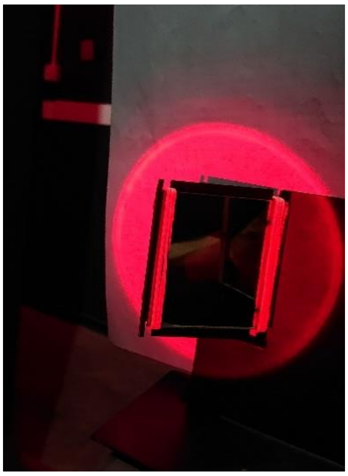

Figure 15 Red circle illuminating the left mirror centrally.

12. If you do not see the red circle very well, you should darken the room.
13. After removing the piece of paper, the red circle should illuminate the (left) mirror centrally (Figure 15).

Adjustment of the second lens

14. Place another lens, with the plane side again facing the operating unit, about 5.0 cm in front of the receiver diode (Figure 16)

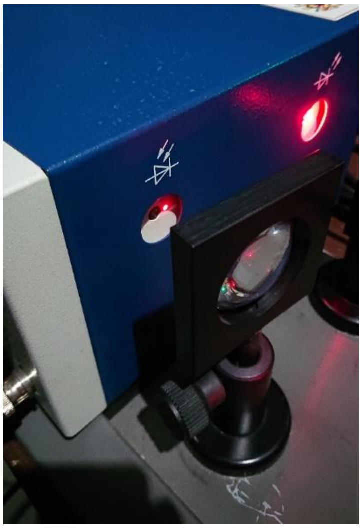

Figure 16 A second lens in front of the receiver diode.

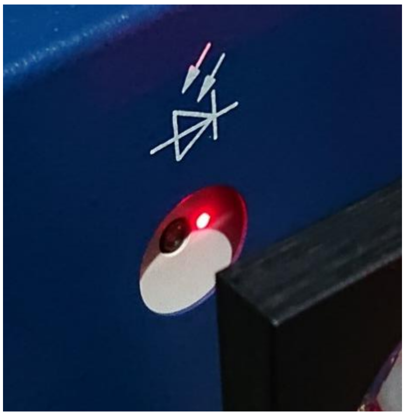

Figure 17 A little red disc of light near the opening of the receiver diode.

15. Move the lens sideways and adjust its height until you see an image of the transmitter diode (a little red circle) on the white ring around the receiver diode. Then, move the lens in the direction of the light beam until the image on the white ring appears as a little disc whose diameter is a little smaller than the opening of the diode (Figure 17).
16. Now, move the lens sideways, and further adjust its height if necessary, so that the image of the transmitter diode hits the receiver diode optimally. For a more accurate adjustment, look at the oscilloscope. It should display an ellipse of maximum amplitude when the adjustment is optimal (Figure 18) (turn the INTEN rotary switch to the right to increase the brightness and adjust the sensitivity accordingly).

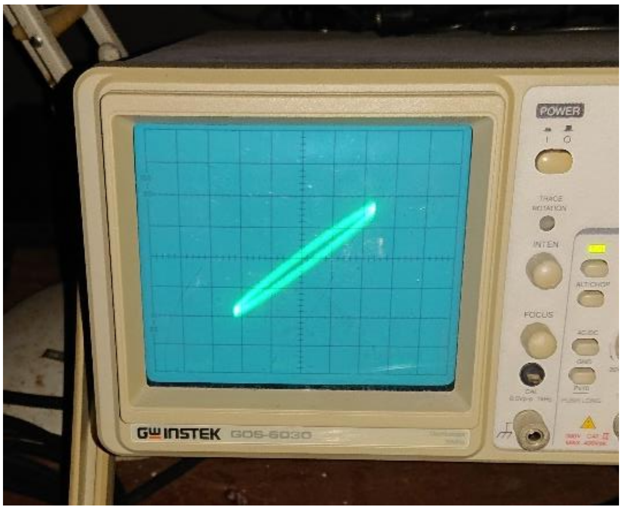

Figure 18 An ellipse is shown on the oscilloscope when the lens and mirror adjustment is optimal.

Optional: adjustment of the mirror

The following steps are not necessary if you have successfully made an optimal adjustment in the previous steps.

17. Check that the mirror is angled such that the reflected beam optimally illuminates the second lens. This can be done by putting a piece of white paper between the operating unit and the second lens (without covering the transmitter diode). The reflected light should illuminate the whole second lens (Figure 19).

Figure 19 An optimal illumination of the second lens.

18. If the illumination is not optimal, adjust the screws at the back of the mirror.

Procedure

Determination of the velocity of light in air

1. Place the mirror near the operating unit so that the slit of the mirror's base points to the zero point of the base plate's scale (Figure 20).

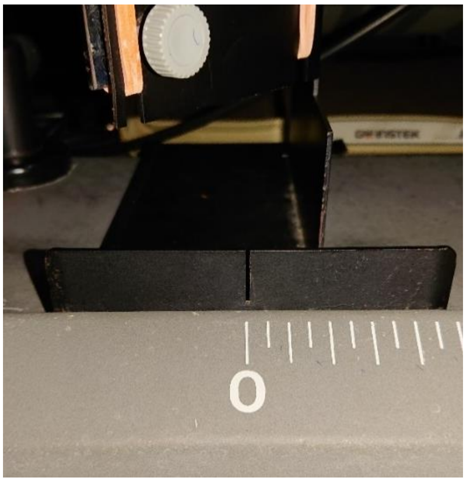

Figure 20 Slit of the mirror's base at the zero point.

2. Change the sensitivity of the X- and Y-channels accordingly to see a Lissajous figure (an ellipse) on the oscilloscope.
3. Turn the phase rotary switch of the operating unit to the right until you see a straight line (Figure 21).

Figure 21 A straight line of negative slope displayed on the oscilloscope.

Take note: Do not use too much force in turning the phase rotary switch. If you cannot get a straight line even after putting the operating unit as left as possible on the base plate and turning the phase rotary switch to the rightmost position, then adjust your initial mirror position. You may put the mirror, say, at 1.0 cm as the initial position.

4. Now, move the mirror away from the operating unit until you see a straight line sloping into the opposite direction (Figure 22). Adjust the sensitivity as required if the figure is too small or too large.

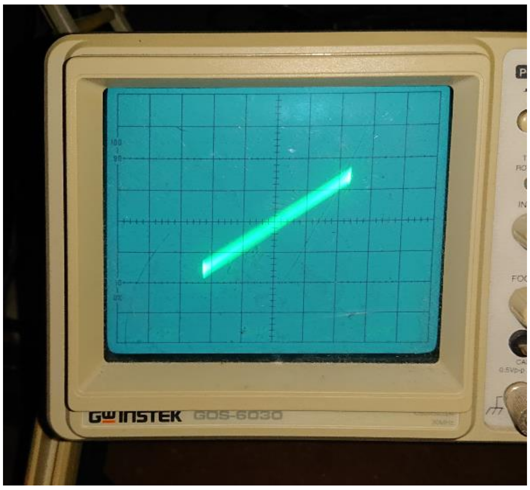

Figure 22 A straight line of positive slope displayed on the oscilloscope.

5. Measure the distance Δx that you had to move the mirror and note this value.
6. Repeat the experiment 10 times.

Determination of the velocity of light in water and synthetic resin

1. Fill the black tube with water and place it on the base plate in such a way that the light beam passes through the tube either on its way to the mirror or on its way back to the receiver diode (Figure 23).

Figure 23 A tube filled with water put on the base plate.

2. Place the mirror directly behind the tube.
3. Note the position of the mirror as x_1.
4. On the display of the oscilloscope, there will appear a Lissajous figure again.
5. Use the phase rotating switch of the operating unit again to display a straight line on the oscilloscope.
6. Then, take the tube out of the light beam and move the mirror away from the operating unit until you see a straight line sloping in the same direction again.
7. Record the new position of the mirror x_2.
8. Repeat the experiment 10 times.
9. After finishing the measurements with the water-filled tube, repeat the procedures above using the synthetic resin block (Figure 24).

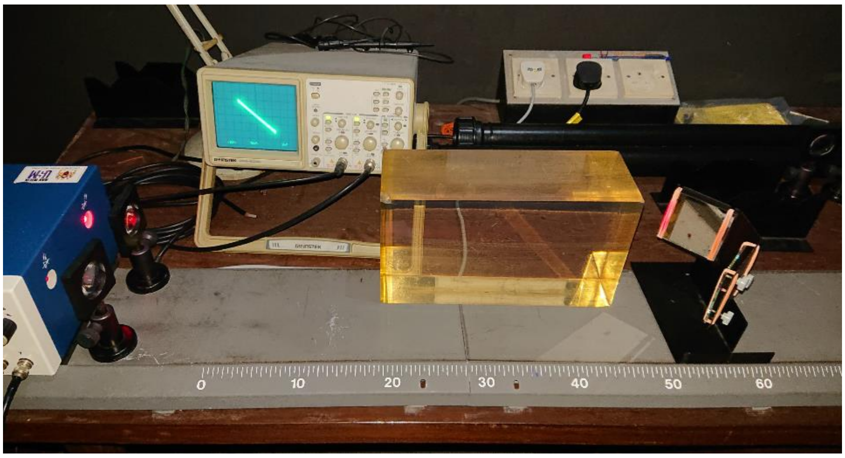

Figure 24 A synthetic resin block put on the base plate.