P73.36 ENS LYON

Practical Experiments

PHY11 Debye-Sears Effect
PHY12 Projection of Standing Waves
PHY17 Acousto-Optical Modulation at Standing Waves

This document contains suggestions and instructions on practical experiments that can be carried out with the SC600 and appropriate accessories. Brief descriptions of and information on the required equipment, setting-up and performance can be found in our catalogue, on our website, and in the user manual of the SC600.

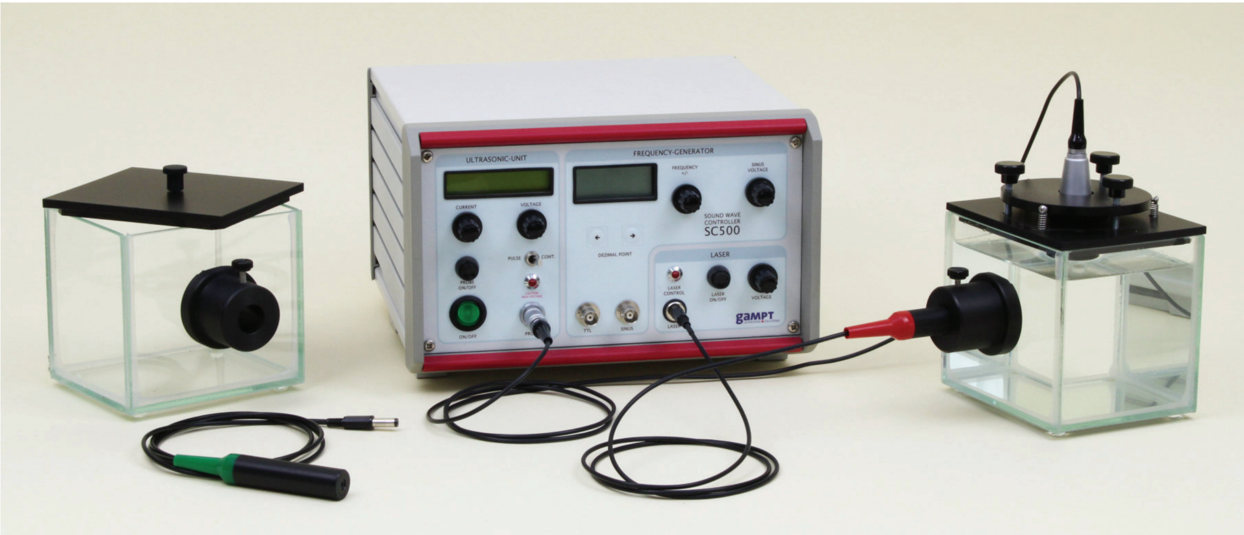
General Experiment Instructions

The following instructions should be adhered to in order for the experiments to work:

- If possible, degassed water is to be used because air bubbles interfere with the sound field as well as the course of the laser light.
- Air bubbles on the ultrasonic probe are to be removed.
- The largest possible distances between the sample vessel and projection wall are to be used, in order to enlarge the spacings between the diffraction orders and to minimise measurement mistakes.
- If no measurement is being carried out, the ultrasound should be switched off in order to prevent the sample liquid from heating up.
- For exact measurements, the temperature should be determined and compared.
- For all frequencies up to 9 MHz, with higher voltages and a good orientation of the transducer, at least two to three diffraction maxima should be visible.
- The projection test is substantially more sensitive to tilting of the transducer than to light diffraction. In the case of projection, the requirements for producing a standing wave must be more closely adhered to.

Attention!
Please consider the safety and operation instructions contained in the SC600 operating manual.

PHY11 Debye-Sears effect



Keywords: Debye-Sears effect, diffraction of light, diffraction grating, diffraction maxima, wavelength, sound velocity, standing and travelling wave

1 Purpose

The experiment shows the diff raction of light at a standing ultrasonic wave (Debye-Sears effect) in a transparent liquid (e. g. water). The sound velocity in the liquid is determined using the dependence of the diffraction maxima on the wavelength of the diffracted laser light and the frequency of the ultrasonic wave.

2 Basics

In 1932 Debye and Sears showed that light undergoes diffraction when passing through a liquid being excited into high-frequency vibrations. By means of this effect, ultrasound can be made more or less "visible". When this effect is used, the density maxima and minima produced in the liquid by a standing or travelling ultrasonic wave act like an optical diffraction grating. The grating constant of such a grating produced by an ultrasonic wave corresponds to the wavelength of this ultrasonic wave. It can be determined by means of the diffraction patterns of the light of a laser beam of known wavelength. Because the wavelength is defined by frequency and sound velocity, the Debye-Sears effect can be used in this experiment set-up to determine - with a high degree of precision - the sound velocity in the liquid thorough which the sound is passing. If the distance s between ultrasonic wave and diffraction pattern, the number N of diffraction maxima, the distance x between the –Nth and +Nth diffraction order, the sound frequency f and the wavelength λ_L of the laser light are known, the wavelength of the sound λ_s and the sound velocity c in the liquid can be calculated according to the following formulae:

$$\lambda_S = 2N \cdot \lambda_L \frac{s}{x} \tag{1}$$

$$c = \lambda_S \cdot f \tag{2}$$

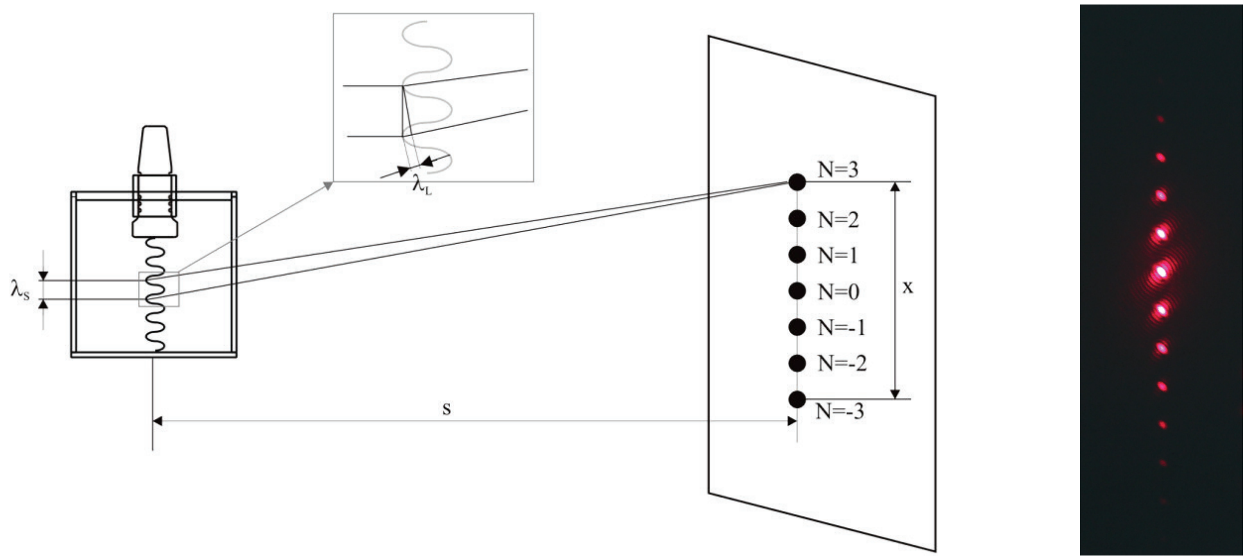


Fig. 1: Diagram of the geometric conditions for the Debye-Sears test and diffraction patterns for red laser light

Example Measurements:

Liquid	Given Values		Measured Values			Calculated Values		Literature Values
	f in MHz	λ_L in nm	N	s in m	x in cm	λ_S in µm	c in m/s	c in m/s
Water	4	650 (rot)	4	2.9	4.1	367.8	1,471	1,480 at 20 °C
Glycerine	4	650 (rot)	2	2.9	1.6	471.2	1,885	1,900 at 25 °C

3 Equipment

- cw generator SC600 order no. 20100
- Debye-Sears set order no. 20200
- Laser module (green) order no. 20211
- AOM sample reservoir order no. 20225
- Cover for AOM sample reservoir order no. 20223

4 Procedure

The distance s between the ultrasonic transducer and the diffraction image is measured by a ruler. The maximum order of diffraction N is determined and the distance between the –Nth and the +Nth order of diffraction x is measured by a calliper or a ruler. The measuring is carried out for all frequencies in the range from 1 MHz on in 1MHz steps, as long as diffraction maxima are visible and separable. The measurement is performed for red as well as green laser light. From the measured values the wavelength of sound λ_s is determined after (1) and with the known frequency f the sound velocity c is obtained using (2). (The measurement can be done also for the second liquid (e. g. alcohol).)

Attention!
Please consider the safety and operation instructions contained in the SC600 operating manual.

5 Results

Diffraction patterns

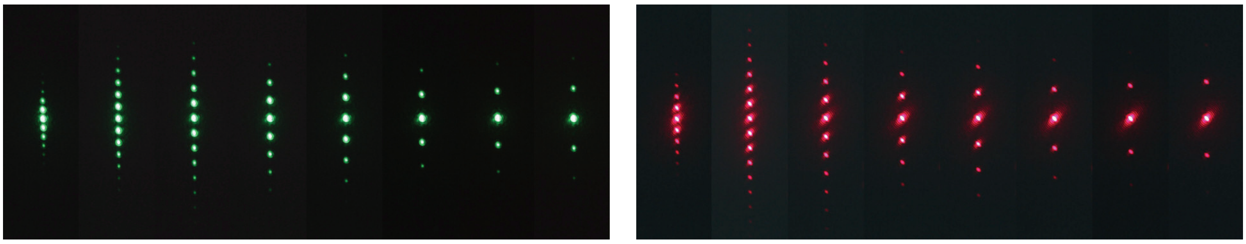


Fig. 2: Diffraction patterns of green laser light (left) and red laser light (right)

The above figure shows typical diffraction patterns for green and red laser light at a standing ultrasonic wave in water at sound frequencies from 3 MHz to 10 MHz (increment: 1 MHz). As the ultrasonic frequency is raised, the distances between the individual diff raction maxima also increase, although the longer-wave red laser light is more strongly diffracted. The number of orders of diff raction is largely determined by the transmission characteristics of the sound probe and the frequency-dependent attenuation.

Measurements

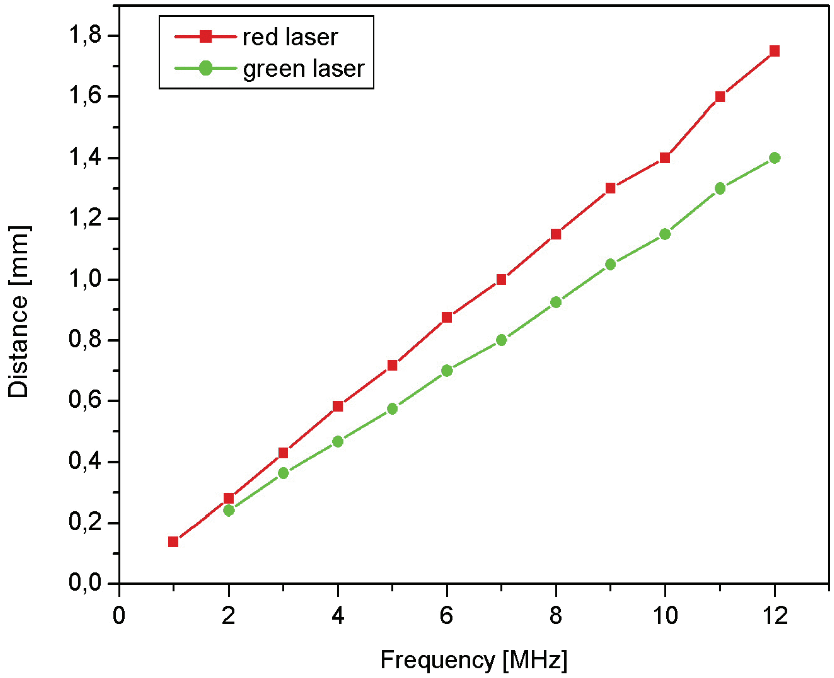
Green laser: λ_L = 532 nm, s = 325cm

f [MHz]	N	x [cm]	x/(2N) [cm]	λ_s [µm]	c [m/s]
1					
2	5	2.4	0.240	720.4	1441
3	4	2.9	0.363	477.0	1431
4	3	2.8	0.467	370.5	1482
5	2	2.3	0.575	300.7	1503
6	2	2.8	0.700	247.0	1482
7	2	3.2	0.800	216.1	1513
8	2	3.7	0.925	186.9	1495
9	2	4.2	1.050	164.7	1482
10	2	4.6	1.150	150.3	1503
11	1	2.6	1.300	133.0	1463
12	1	2.8	1.400	123.5	1482
				mean	1479
				SD	26

Red laser: λ_L = 652 nm, s = 325cm

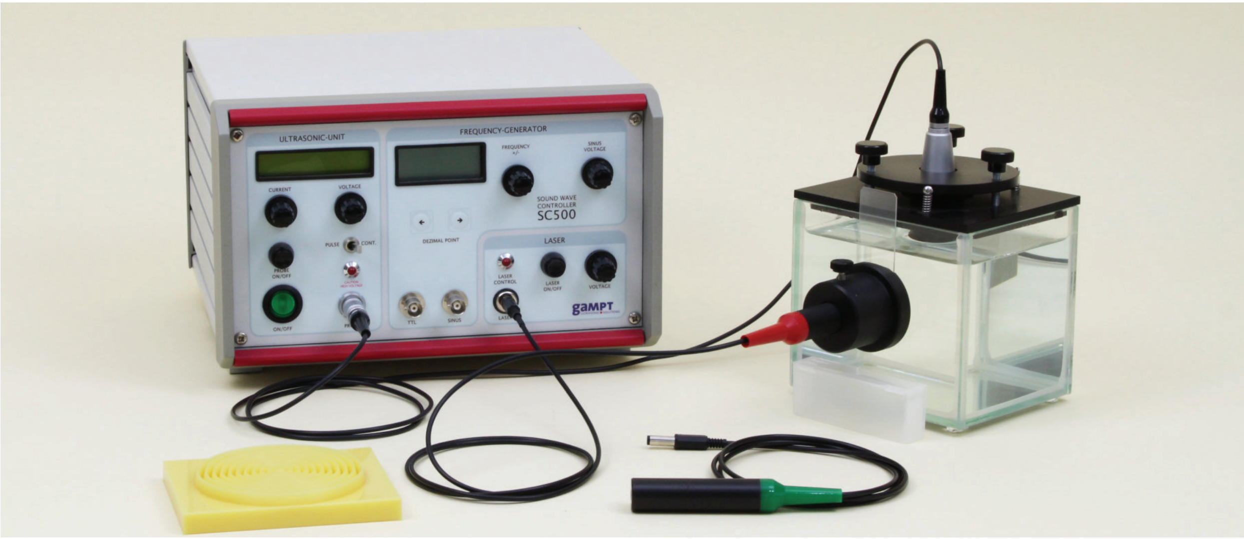
f [MHz]	N	x [cm]	x/(2N) [cm]	λ_s [µm]	c [m/s]
1	9	2.5	0.139	1525.7	1526
2	5	2.8	0.280	756.8	1514
3	5	4.3	0.430	492.8	1478
4	5	3.5	0.583	363.3	1453
5	3	4.3	0.717	295.7	1478
6	2	3.5	0.875	242.2	1453
7	2	4	1.000	211.9	1483
8	2	4.6	1.150	184.3	1474

f [MHz]	N	x [cm]	x/(2N) [cm]	λ_s [µm]	c [m/s]
9	2	5.2	1.300	163.0	1467
10	1	2.8	1.400	1581.4	1514
11	1	3.2	1.600	132.4	1457
12	1	3.5	1.750	121.1	1453
				mean	1479
				SD	26



As expected from equation (1) with increasing ultrasonic frequency an increase of the distance of diffraction orders can be seen. When comparing the distances of diffraction orders for the same ultrasonic frequency but with different laser lights, red light gives larger distances. The number of diffraction orders is determined mainly by the transmission characteristics of the probe and the frequency attenuation. The main error results from measuring the distances of the diffraction orders x. This can be reduced applying a larger distance s or a suitable optical projection. The mean sound velocity of 1479 m/s lies near the theoretical value of 1482 m/s at 20 C.

PHY12 Projection of standing waves



Keywords: Sound wavelength, sound velocity, standing and travelling wave, divergent monochromatic light, refraction indices, focal length of an optical lens

1 Purpose

In the experiment a standing ultrasonic wave in a liquid is imaged by means of divergent laser light. The dependence of the brightness modulation of the projection images produced upon the wavelength of the light and the frequency of the ultrasonic wave is investigated and the sound velocity in the liquid (water) is determined.

2 Basics

A standing ultrasonic wave in a liquid can be directly imaged by means of divergent monochromatic light. Due to the standing wave, sound pressure differences are produced in the liquid which repeat periodically along the sound beam axis. The localised density differences caused by this result in spatially differing and periodically repeating refraction indices along the sound beam axis. When monochromatic light is used, the projection of the standing wave therefore shows a light-dark modulation with periodically repeating brightness maxima which correspond to the density differences.

To determine the wavelength from the distribution pattern and the geometry, refraction corrections due to the glass walls and the measuring liquid must still be taken into account as well as the focal distance f of the lens in air. To determine the wavelength exactly, it is therefore recommended that the method of light refraction be used, as described in experiment PHY11.

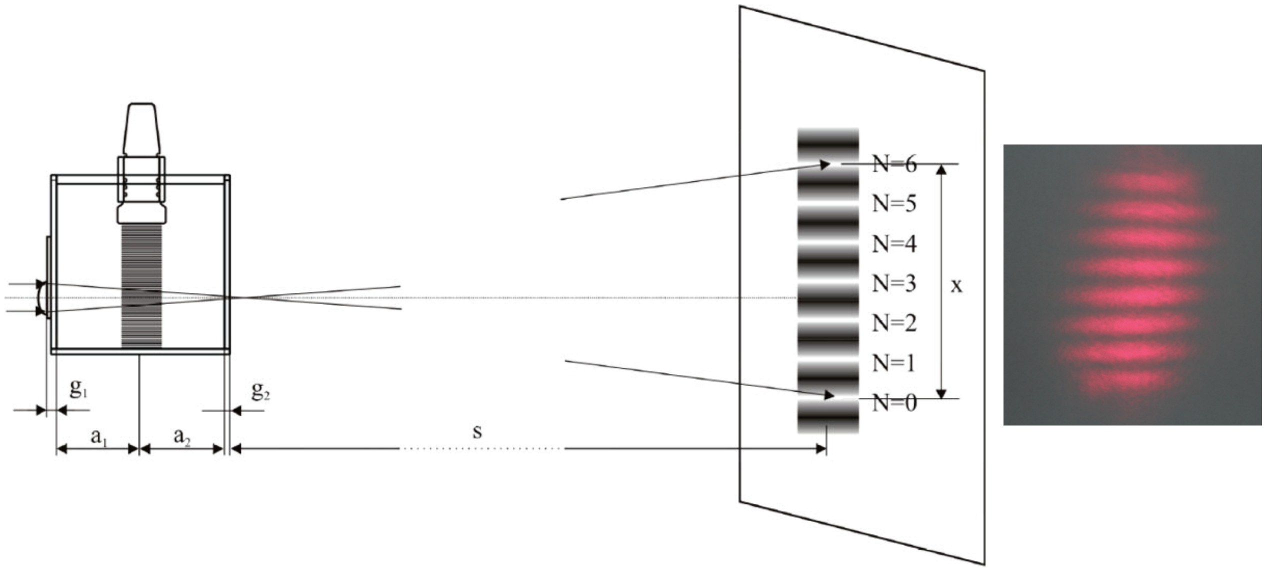


Fig. 1: Diagram of the geometric conditions during the projection of a standing ultrasonic wave and projection pattern for red laser light

$$\lambda_S = \frac{2x}{N} \cdot \frac{l_{foc} - \frac{g_1}{n_G} - \frac{a_1}{n_L}}{s - \left(l_{foc} - \frac{g_1 + g_2}{n_G} - \frac{a_1 + a_2}{n_L} \right)} \tag{1}$$

$$c = \lambda_S \cdot f \tag{2}$$

The formula (1) states the exact calculation rule for the sound wavelength λ_S from the projection image. The spacing a_1 between sound field and glass wall on the lens side and the distance a_2 can be assumed, as an approximation, to be half of the respective inside dimension. The thickness of the glass g_1 corresponds to the sum of the wall thickness of the glass vessel and the thickness of the glass substrate of the projection lens. The refraction indices n_L of the measurement liquid and n_G of the glass must be determined or taken from the literature. N is the number of the brightness maxima and x the respective distance. The sound velocity in the liquid is again calculated according to the equation (2).

Example Measurement for Water:

Given values:	focal distance of the lens in air:	l_{foc}	= 10 cm
	refraction index of glass:	n_G	= 1.45
	refraction index of water:	n_L	= 1.33
	sound frequency:	f	= 4 MHz

Table 1: summary of the measurement values and results

Measured Values						Calculated Values		Literature
$a_{1,2}$ in cm	g_1 in cm	g_2 in cm	s in m	x in cm	N	λ_S in µm	c in m/s	c in m/s
4.8	0.5	0.4	3.03	8.9	9	397	1590	1,480 at 20 °C

3 Equipment

- cw generator SC600 — order no. 20100
- Debye-Sears set — order no. 20200
- Laser module (green) — order no. 20211
- Projection lens — order no. 20230
- Cover for AOM sample reservoir — order no. 20223

4 Procedure

The projection lens is inserted into the laser support and by that into the optical path. The distance between the edge of the vessel and the diffraction image s is measured by a ruler. The number of brightness maxima N is determined and the distance x is measured by a calliper or a ruler. The measurement is done for all frequencies in the range from 1 MHz on in steps of 1 MHz, as long as a projection image can be observed. The measurement is carried out for red as well as for green laser light. From the results of measurement the wavelength of sound λ_S is determined after (1) and using the known frequency f the velocity of sound c is determined after (2). The values are compared for the different laser wavelengths and deviations to values from the literature discussed.

With the ultrasonic absorber can be demonstrated that the standing waves and the projection image disappear but the diffraction stays (Debye-Sears effect).

Attention!
Please consider the safety and operation instructions contained in the SC600 operating manual.

5 Results

Projection patterns

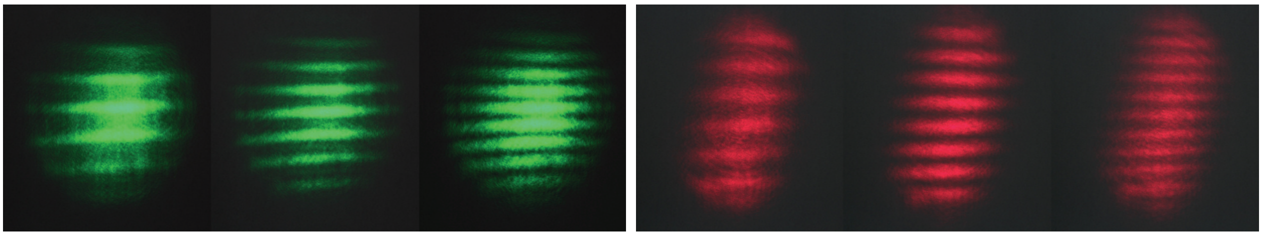


Fig. 2: Projection patterns of green laser light (left) and red laser light (right)

The above projection images of standing ultrasonic waves in water (here at 2.8 MHz, 3.5 MHz and 4.5 MHz) obtained with green and red laser light show the reduction of the spacing of the brightness maxima to be expected with increasing sound frequency. The diff erence between green and red laser is here caused by the wavelength dependence of the refraction indices.

Measurements

a_1 = 4.05 cm, a_2 = 5,65 cm, s = 280 cm, g_1= 4.9 mm, g_2 = 3.9 mm, T = room temperature,
f = 10 cm, n_G = 1.45, n_L = 1.33

Green laser: λ_L = 532 nm

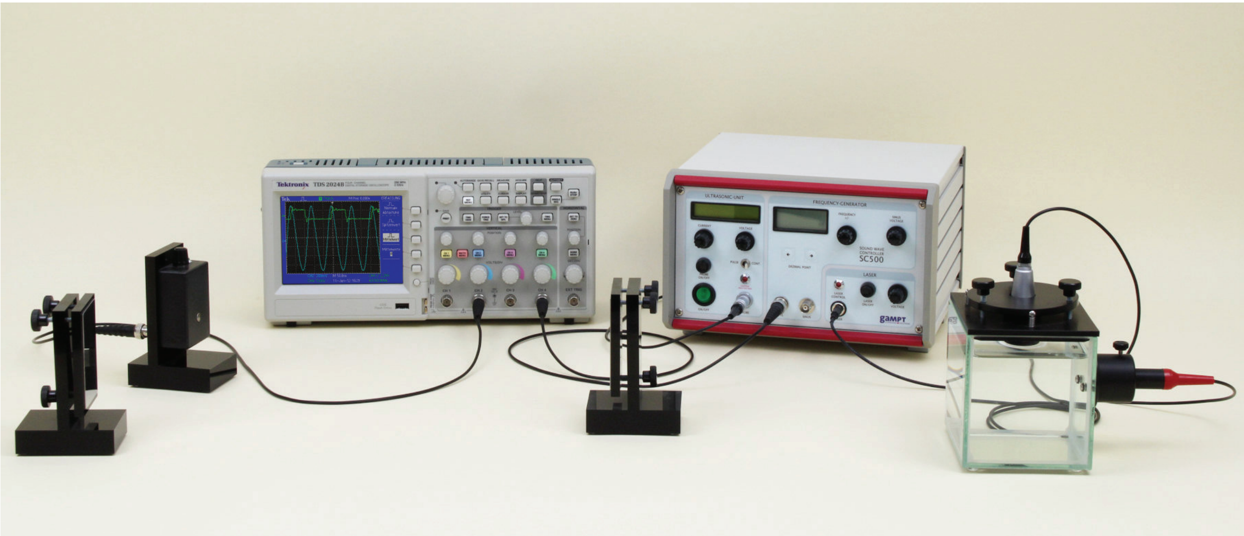
f [MHz]	N	x [cm]	λ_s [µm]	c [m/s]
2	2	4,9	782	1564
3	3	5.0	532	1596
4	5	6.2	396	1583
			mean	1581

Red laser: λ_L = 652 nm

f [MHz]	N	x [cm]	λ_s [µm]	c [m/s]
2	3	6.6	702	1404
3	4	6.3	503	1508
4	7	7.8	356	1423
			mean	1445

As expected from equation (1) the distance of brightness maxima decreases with increasing ultrasonic frequency. The determined sound velocity values deviate strongly from the literature value for water (1482 m/s at 20 °C), whereas the value for green light is greater than for red light. This error results from the change of the focal length of the lens due to transmission through the glass plates and the measuring liquid. The difference between green and red light is explained by the wavelength dependence of the refraction indices.

PHY17 Acousto-optical modulation at standing waves



Keywords: Acousto-optical effect, standing ultrasonicwave, sound wavelength, diffraction, optical grating, grating constant, amplitude modulation, phase shift

1 Purpose

The acousto-optical effect of the amplitude and phase modulation of light diffracted at a standing ultrasonic wave is investigated. The effect is used to determine sound velocity in water.

2 Basics

Commensurate with the Debye-Sears eff ect (PHY11), light is diff racted at a standing or travelling ultrasonic wave in a liquid or a solid body. The diffraction maxima produced with the diffraction at a standing ultrasonic wave are amplitudemodulated. The amplitude is modulated with twice the ultrasound frequency.

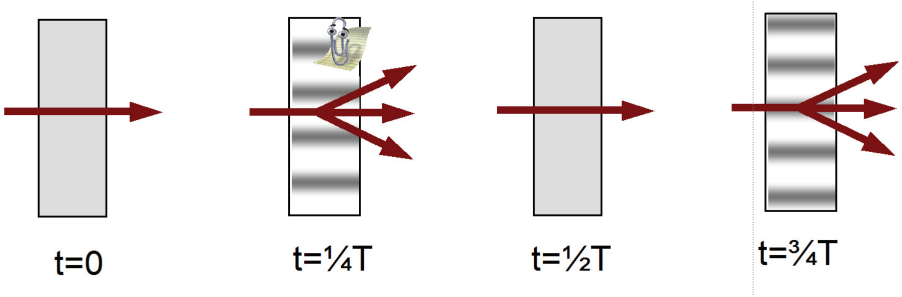


Fig. 1: Light diffraction at a standing wave (T = periode = 1/f)

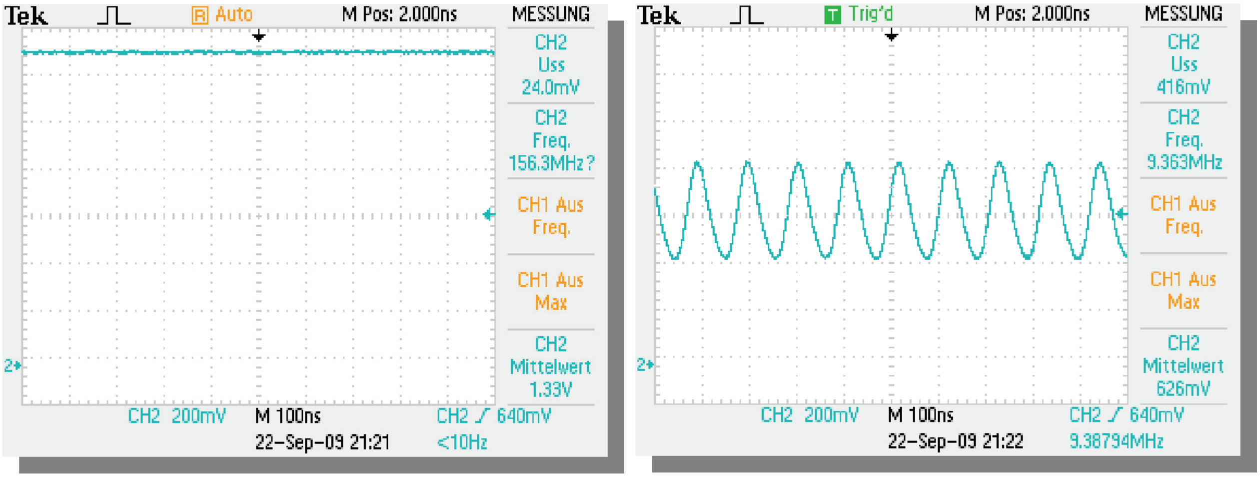


Fig. 2: Oscilloscope copies (left: ultrasound off; right: ultrasound on)

Furthermore there is a phase shift of 180° occurs between the maximum of 0th and a maximum of nth order.

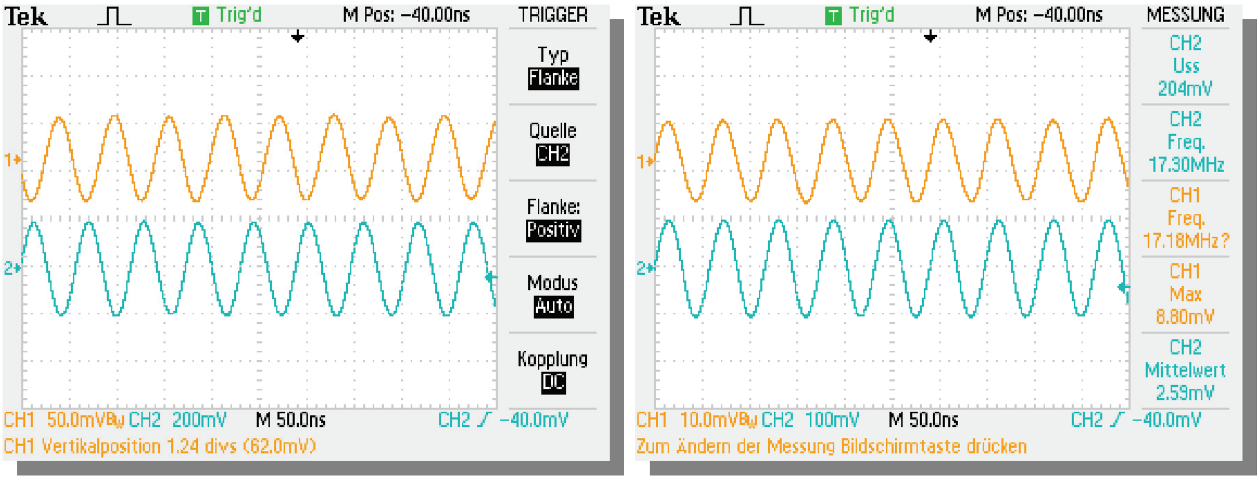


Fig. 3: Oscilloscope copies (left: 0th and 1st order; right: 1st and 2nd order)

The amplitude and phase modulation effects are used in acousto-optical modulators (AOMs).

Using photodiodes and an oscilloscope, amplitude modulation and phase shift can be demonstrated. A change in the sound frequency influences the modulation amplitude.

Using amplitude modulation for determining soud velocity

The modulation amplitude is always biggest when the distance h between ultrasonic transducer and sound refl ector corresponds to a multiple m of half of the sound wavelength λ.

$$h = m * \frac{\lambda}{2} \tag{1}$$

Because of the change in frequency the number of half wavelengths will be reduced by Δm. For the particular modulation maximum , it follows:

$$h = (m + \Delta m) * \frac{\lambda_{m+\Delta m}}{2} \tag{2}$$

For waves is

$$\lambda = \frac{c}{f} \tag{3}$$

Therefore m can be calculated from

$$m = \frac{\Delta m * f_m}{\Delta f} \qquad (4)$$

This makes it possible to determine the sound velocity c in the medium according to

$$c = \frac{2 * h * \Delta f}{\Delta m} \qquad (4)$$

The sound velocity can be determined by variation of the ultrasonic frequency and the determination of the modulation maxima (standing wave).

3 Equipment

- cw generator SC600 — order no. 20100
- Debye-Sears set — order no. 20200
- Beam splitter — order no. 20301
- 2 adjustable reflectors — order no. 20302
- 2 photodiode receivers — order no. 20303
- Oscilloscope — -

4 Procedure

The laser, the adjustable and the semipermeable reflectors and the probe shall be adjusted in a way, that an optimal diffraction image will develop. The intensity of the higher orders and the distances between the diffraction maxima should be as large as possible.

Amplitude modulation effect

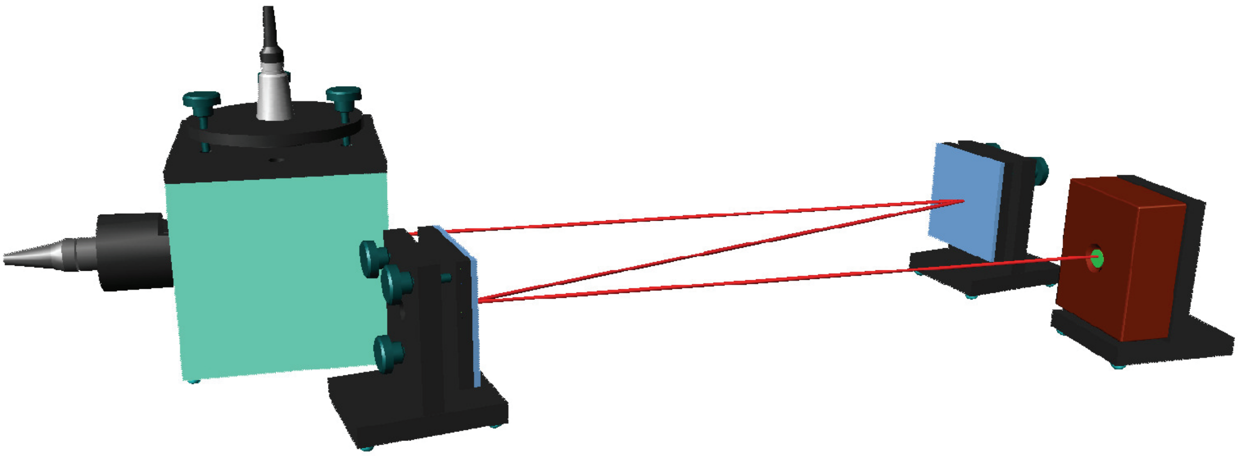


Fig. 4: Schematic setup with one photodiode receiver

For measurements regarding the amplitude modulation effect a setup with one photodiode receiver will be used. It shall be adjusted in a way that the 0-th order hits the photodiode. It requires a long light way since the best results will be achieved with sound frequencies between 3 and 5 MHz, but the diffraction maxima are very close together at these frequencies. The complete setup (also the ultrasonic probe) shall be readjusted until the amplitude modulation is maximal. The the generator`s frequency shall be attuned in 100 Hz steps until the amplitude modulation reaches a maximum again. The frequency change shall be registered and the procedure repeated ca. 5 times. With the measured distances between the bottom side of the ultrasonic probe and the bottom of the reservoir and the frequency changes the sound velocity of the test liquid can be calculated.

Phase modulation effect

For measurements regarding the phase modulation effect a setup with one photodiode receiver will be used. Ultrasonic frequencies around 5 MHz are very suitable for this. With one photodiode receiver the 0-th order will be detected on the oscilloscope and with the second photodiode receiver a higher order (1-st, 2-nd, ...). The modulation shall be measured compared to the total amplitude. The phase shift between the orders shall be measured. The frequency of the modulation shall be measured.

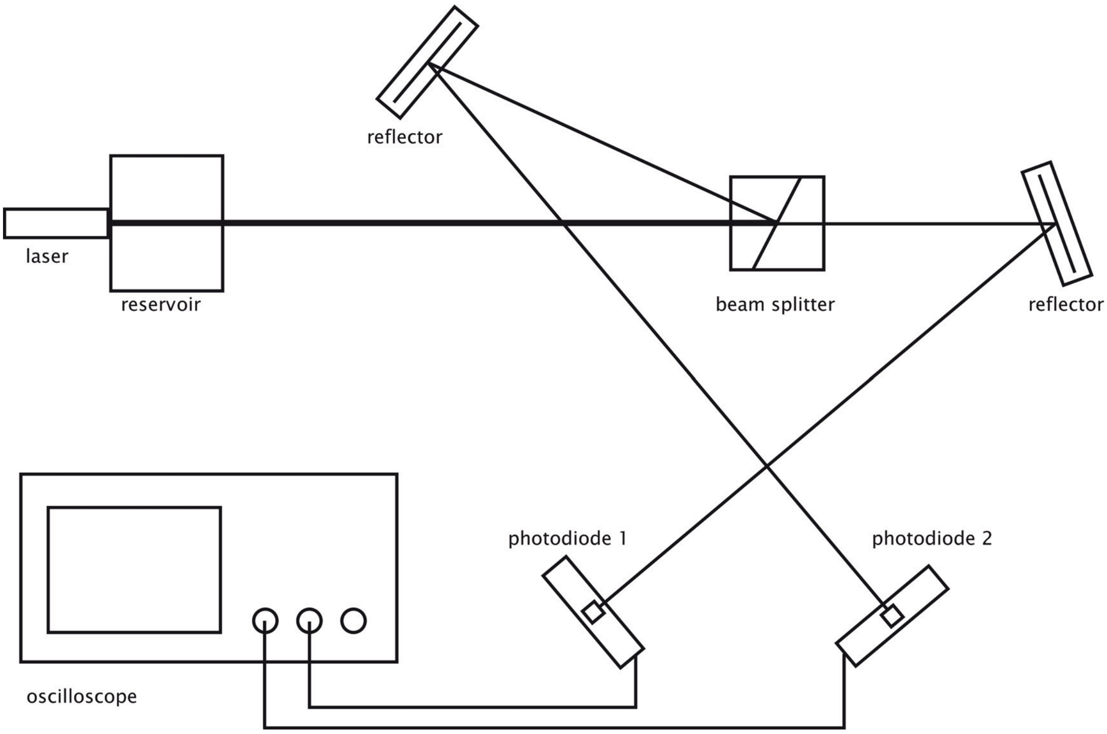


Fig. 5: Schematic setup using two two photodiode receivers and one beam splitter

Attention!
Please consider the safety and operation instructions contained in the SC600 operating manual.

5 Results

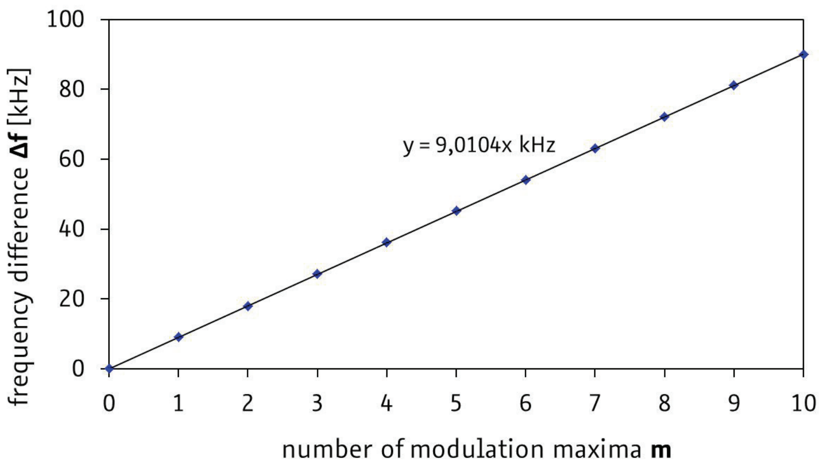
Amplitude modulation

To determine the sound velocity in water, the 0th order of diffraction was aligned to a photodiode and a fi rst maximum amplitude was searched for. Afterwards, the sound frequency was gradually increased and the frequencies of the following maximum amplitudes were determined.

Measurement values:

m	F [MHz]	Δ[kHz]	c [m/s]
0	4.7209	0.0	
1	4.7300	9.1	1511
2	4.7388	17.9	1486
3	4.7481	27.2	1505
4	7.7571	36.2	1502
5	4.7661	45.2	1501
6	4.779	54.2	1494
7	4.7839	63.0	1494
8	4.7930	72.1	1496
9	4.8020	81.1	1496
10	4.8109	90.0	1494
		mean	1498
		SD	7

h = 83 mm; T(H2O) = 25 °C



For the measuring points entered in the diagram, there arises a sound velocity in water of (1498 ± 7) m/s (T = 25 °C).

Phase modulation

The laser beam was splited with a beam splitter to determine the phase shift. The second partial beam was aligned to a second photodiode, so that another diff raction maximum could be obtained with it. The phase shift between the two diff erent orders of diff raction were determined at the oscilloscope.

Modulation amplitude at f= 4,73 MHz

0-th ordner:	600-800 mV
1-st order:	200-300 mV
2-nd order:	50-100 mV
Phase shift 0-th to 1-st order:	180°
Phase shift 0-th to 2-nd order:	180°
Phase shift 1-st to 2-nd order:	0°
Modulation frequency:	9.46 MHz