# Phase and group velocity of ultrasonics in liquids



## Related topics

Longitudinal waves, velocity of sound in liquids, wavelength, frequency, piezoelectric effect, piezoelectric ultrasonics transformer.

## Principle and task

The sound waves transmitted to a liquid by the ultrasonic generator are picked up by a piezoelectric ultrasonic pick-up and the signal from transmitter and receiver compared on an oscilloscope.
The wavelength is determined and the phase velocity calculated from the relative phase position of the signals. The group velocity is determined from measurements of the sound pulse delay time.

## Equipment

| | | |
|---|---|---|
| Ultrasonic pickup | 11744.00 | 1 |
| Ultrasonic generator | 11744.93 | 1 |
| Glass cell, 150×55×100 mm | 03504.00 | 1 |
| Insulating support | 07924.00 | 1 |
| Optical profile bench l = 60 cm | 08283.00 | 1 |
| Base f. opt. profile-bench, adjust. | 08284.00 | 2 |
| Slide mount f. opt. pr.-bench, h 30 mm | 08286.01 | 2 |
| Slide mount f. opt. pr.-bench, h 80 mm | 08286.02 | 1 |
| Table top on rod | 08060.00 | 1 |
| Swinging arm | 08256.00 | 1 |
| Right angle clamp -PASS- | 02040.55 | 1 |
| Support rod, stainl.steel, 500 mm | 02032.00 | 1 |
| Universal clamp | 37715.00 | 1 |
| Oscilloscope, 20 MHz, 2 channels | 11454.93 | 1 |
| Connecting cord, 100 mm, red | 07359.01 | 1 |
| Screened cable, BNC, l 750 mm | 07542.11 | 2 |
| Adapter, BNC-socket/4 mm plug pair | 07542.27 | 1 |
| Thermometer -10...+30 C | 05949.00 | 1 |
| Glycerol 250 ml | 30084.25 | 3 |
| Sodium chloride 500 g | 30155.50 | 1 |
| Water, distilled 5 l | 31246.81 | 1 |

## Problems

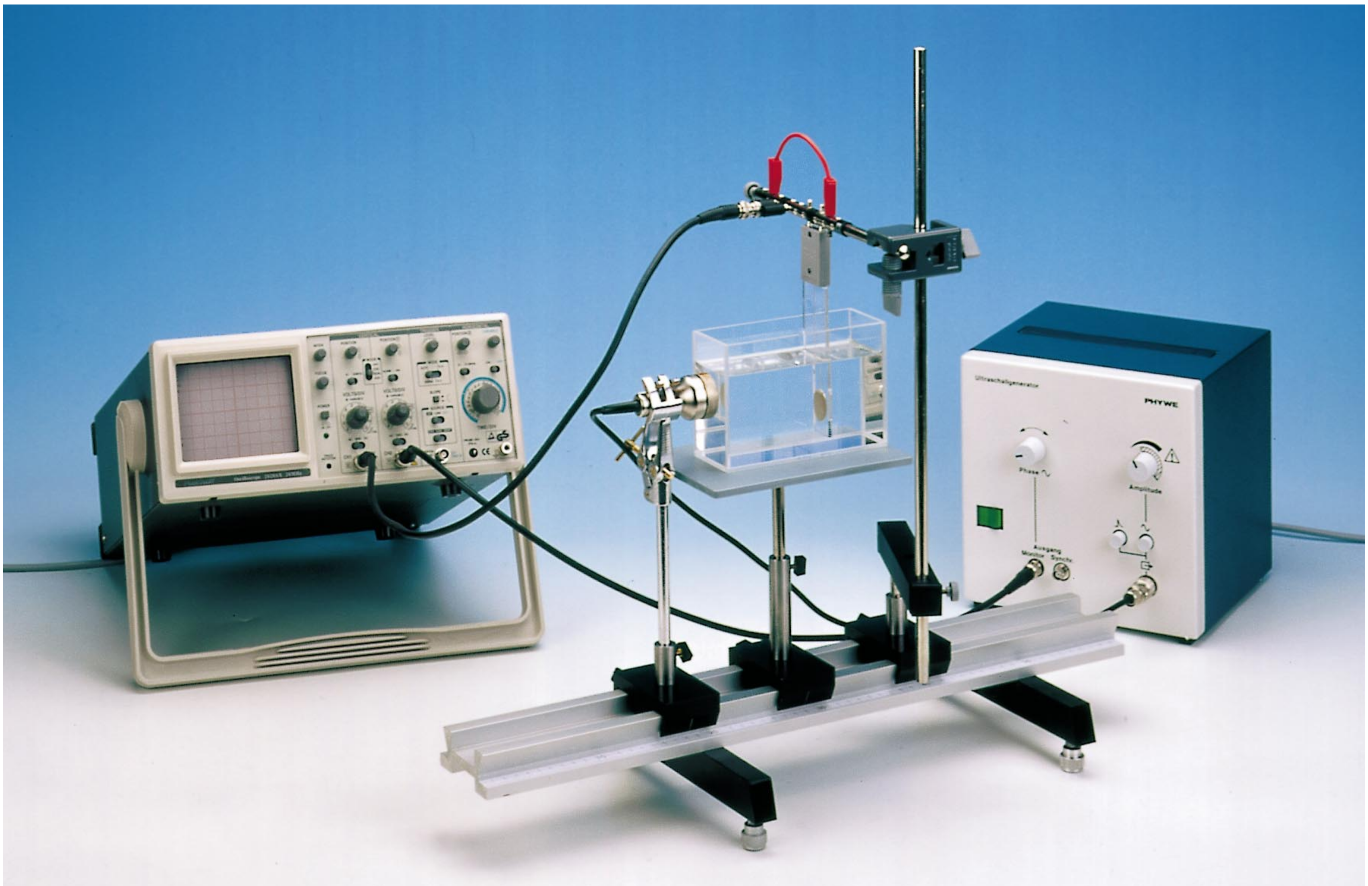
The signals from the ultrasonic generator and the ultrasonic pick-up are recorded on the oscilloscope.

1. To measure the relative phase position of the signal from the ultrasonic pick-up as a function of its distance from the ultrasonic generator (which is in the sine mode), and to determine the ultrasonic wavelength and the phase velocity when the frequency is known.

2.1. To determine the oscilloscope's coefficient of sweep with the aid of the ultrasonic frequency.

2.2. With the generator in the pulsed mode, to record the delay time of the sound pulses as a function of the distance between a generator and the pick-up, and to determine the group velocity.

Fig. 1: Experimental set-up for investigating the velocity of propagation of ultrasonics in liquids.



**Set-up and procedure**

The experiment is set up as shown in Fig. 1. The sound-radiating surface of the generator is wetted with glycerol or water in order to improve the connecting and rests against the wall of the glass cell.

In order to avoid stationary waves and multiple echoes through sound relfection, the cell wall opposite the generator is covered with sound-absorbing material such as foam or crumpled paper.

1. The oscilloscope is triggered internally via channel 2 by the monitor signal from the ultrasonic generator.
   The pick-up and monitor signals are set in phase on the screen by moving the pick-up and the phase setting on the generator. The pick-up is moved from this setting and the wavelength determined from the distance $\Delta l$ by which it was moved and the number $n$ of passages in the same phase that were convered thereby.

2.1. The time base is calibrated with the known generator frequency when the oscilloscope time base best suited to the delay time has been estimated.

2.2. The oscilloscope is triggered externally by the synchronous signal of the generator which is set to the pulsed mode. The ultrasonic pick-up is moved from its initial position close to the generator, and the change in the pulse delay time determined from the displacement of the pulse edge on the oscillogram. The temperature of the liquid is measured.
The measurement is made for water, glycerol and sodium chloride solution.

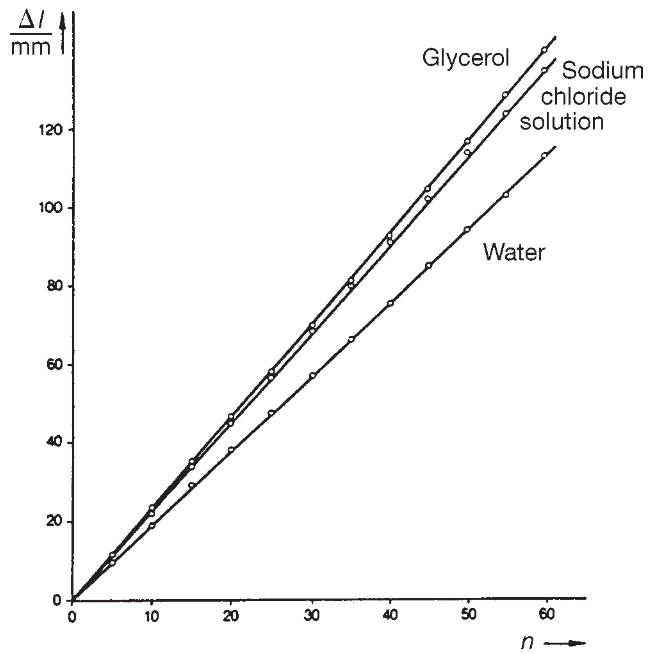



Fig. 2: Detector displacement $\Delta l$ as a function of the number $n$ of wavelengths covered, for water, glycerol and sodium chloride solution (temperature $\vartheta$ = 25 °C).

**Theory and evaluation**

Problem 1:

With a change $\Delta l$ in the distance between generator and pick-up, from its inital position (relative phase $\Delta\phi = 0$), the receiver signal phase moves in relation to the transmitter signal by

$$\Delta\phi = \frac{\Delta l}{\lambda} \cdot 2\pi \qquad (1)$$

When the distance changes further, the signal overlap again for:

$$\Delta\phi = n \cdot 2\pi \qquad n = 1, 2 \ldots \qquad (2)$$

The wavelength $\lambda$ can be determined as

$$\lambda = \frac{\Delta l}{\Delta\phi} \cdot 2\pi = \frac{\Delta l}{n} \qquad (3)$$

from equations (1) and (2).

When the sound frequency $f$ is known, the phase velocity is

$$c_p = \lambda \cdot f \qquad (4)$$

The wavelength $\lambda$ is obtained from (3) as a slope of the regression line.

Table 1 shows the wavelenghts $\lambda$ with the standard errors $\Delta\lambda$ and the phase velocities calculated at a frequency $f$ = 800 kHz in accordance with (4). The error for the phase velocity $\Delta c_p$ is given by $\Delta\lambda$ and the error for the frequency $\delta f$ = +5 kHz.

Table 1

| Liquid | $\frac{\vartheta}{°C}$ | $\frac{\lambda}{mm}$ | $\frac{\Delta\lambda}{mm}$ | $\frac{c_p}{m/s}$ | $\frac{\Delta c_p}{m/s}$ |
|---|---|---|---|---|---|
| Distilled water | 25 | 1.873 | 0.003 | 1500 | 12 |
| Sodium chloride solution (saturated) | 25 | 2.255 | 0.007 | 1800 | 20 |
| Glycerol+ | 25 | 2.353 | 0.004 | 1880 | 15 |

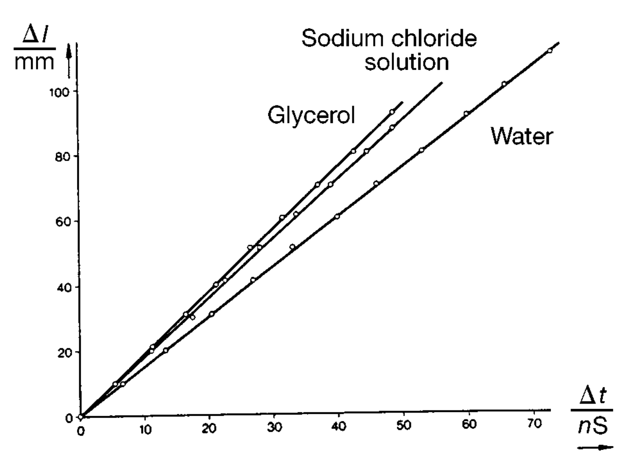



Fig. 3: Change in sound path $\Delta l$ as a function of the change in delay time $\Delta t$, for water, glycerol and sodium chloride solution (temperature $\vartheta$ = 25 °C).

2.1. The coefficient of sweep is obtained as:

$$t^* = \frac{N \cdot T}{x} \quad (5)$$

where:

$N$ = number of vibration periods shown.

$T = \frac{1}{f}$ = duration of the period

($T$ = 1.25 µs when
$f$ = 800 kHz)

$x$ = length of the vibration periods shown on the oscillogram.

2.2. The group velocity $c_G$ is obtained from the changes in the sound path $\Delta l$ and in the delay time $\Delta t$ as:

$$c_G = \frac{\Delta l}{\Delta t} \quad (6)$$

Table 2 shows the group velocities obtained as a slope of the regression line in accordance with equation (6) and with the standard error $\Delta c_G$.

Table 2

| Liquid | $\frac{\vartheta}{°C}$ | $\frac{c_G}{m/s}$ | $\frac{\Delta c_G}{m/s}$ | $\frac{\Delta_M c_G}{m/s}$ |
|---|---|---|---|---|
| Distilled water | 25 | 1506 | 7 | 12 |
| Sodium chloride solution (saturated) | 25 | 1800 | 9 | 14 |
| Glycerol+ | 25 | 1900 | 9 | 15 |

The last column contains the standard mean error $\Delta_M c_G$ obtained from the statistical and systematic errors occurring in the determination of the sweep coefficient at the generator frequency.

Group and phase velocity are interlinked in accordance with:

$$c_G = c_p - \lambda \frac{dc_p}{d\lambda}$$

The fact that the results $c_G = c_p$ agree within the limits of measurement error indicate that

$$\frac{dc_p}{d\lambda} = 0$$

and that there is no dispersion.

Table 3

| Liquid | $\frac{\vartheta}{°C}$ | $\frac{c}{m/s}$ | $\frac{\Delta c/\Delta T}{m/s \cdot °C}$ | Source |
|---|---|---|---|---|
| Glycerol+ | 20 | 1923 | −1.8 | * |
| | 25 | 1904 | −2.2 | ** |
| Water (distilled) | 25 | 1497 | +2.5 | * |
| | 25 | 1498 | +2.4 | ** |
| | | | $(0 < \theta < 40\,°C)$ | |

## Bibliography

* L. Bergmann, Der Ultraschall (Ultrasonics), Hirzel-Verlag

** Handbook of Chemistry and Physics, The Chemical Rubber Co.

## Note

1. As glycerol is hygroscopic, a slower sound velocity is often measured for glycerol which has been allowed to stand.

2. Oscilloscope: relative sweep error ±5 %.

   Ultrasonic generator: relative error for a frequency of 800 kHz: ±0.6 %.

3. According to L. Bergmann, the velocity of sound in a sodium chloride solution increases linearly with concentration. The change in velocity which takes place as the temperature changes is the same as that of water.

   Sound velocity are a function of temperature (see Bibliography).