Temperature dependence of the velocity of sound in liquids

Related topics

Wavelength, frequency, velocity of sound in liquids, compressibility, density, ultrasonics, piezoelectric effect, piezoelectric ultrasonic transducer.

Principle and task

Sound waves are radiated into a liquid by an ultrasonic transmitter and detected with a piezoelectric transducer. The wavelength of the sound is found by comparing the phase of the detector signal for different sound paths and, when the frequency is known, the velocity of sound as a function of the temperature of the liquid is determined.

Equipment

Ultrasonic pickup	11744.00	1
Ultrasonic generator	11744.93	1
Slide mount, lateral. adjust., cal.	08082.03	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	1
Swinging arm	08256.00	1
Insulating support	07924.00	1
Immersion thermostat A100	46994.93	1
Accessory set for A100	46994.02	1
Bath for thermostat, Makrolon	08487.02	1
Lab thermometer, -10..+100C	38056.00	1
Oscilloscope, 20 MHz, 2 channels	11454.93	1
Support rod, l 100 mm	02020.00	2
Right angle clamp -PASS-	02040.55	2
Universal clamp with joint	37716.00	1
Screened cable, BNC, l 750 mm	07542.11	2
Adapter, BNC-socket/4 mm plug pair	07542.27	1
Glycerol 250 ml	30084.25	1
Water, distilled 5 l	31246.81	1
Connecting cord, 100 mm, red	07359.01	1

Problems

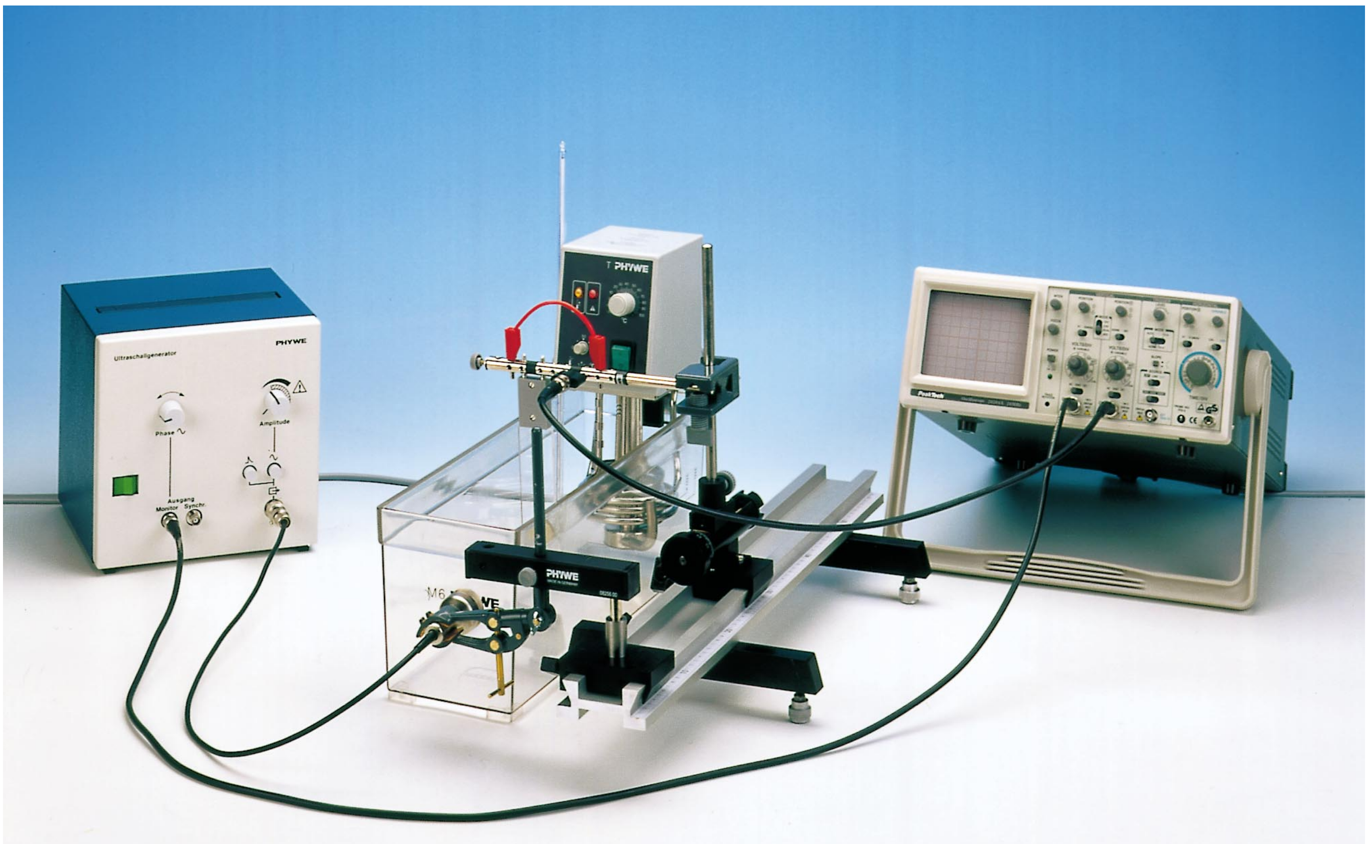
The wavelength is found from the phase position of the sound pickup signal relative to the generator signal as a function of the sound path and the velocity of the sound is determined when the ultrasonic frequency is known. The measurement is made for water and glycerol as the temperatures of the liquids are changed step-by-step.

Set-up and procedure

Fig. 1 shows the experimental set-up. The sound radiating face of the sound transmitter is wetted with glycerol or water for better acoustic coupling and lies flat against the wall of the bath vessel. In order to avoid standing waves due to sound reflection, the wall of the vessel opposite to the sound transmitter is covered with a sound-absorbing material such as foam material or crumpled paper.

The ultrasonic generator is set to sine wave operation. The oscilloscope is triggered internally via channel 1 by means of the generator monitoring signal. The sound frequency is found with the oscilloscope which is connected to the 'Synchr.'

Fig. 1: Experimental set-up: Temperature dependence of the Velocity of sound in liquids.



generator output. The pickup and monitoring signals are set in phase on the screen by moving the sound pickup and adjusting the phase control on the generator. The sound pickup is moved from this starting position and the wavelength is determined from the distance Δl through which it has been moved and the number n of inphase transition points traversed in the process.

In order to obtain an interferencefree signal it is recommended to connect the thermostat heating coil to the oscilloscope earth socket with the crocodile clip.

The experiment is carried out with water and glycerol.

Theory and evaluation

Provided that the oscillatory process is an adiabatic one, the relationship

$$c = \sqrt{\frac{1}{\rho \cdot \beta_{ad}}} \qquad (1)$$

where ρ is the density and β_{ad} the adiabatic compressibility, is obtained for the velocity of sound in liquids.
The change of the velocity of sound with temperature is in the main determined by the temperature dependence of the compressibility.

In all liquids with the exception of water the compressibility increases and the density decreases as the temperature rises. The velocity of sound decreases approximately linearly as the temperature rises. Water occupies a special position amongst liquids; the compressibility is reduced initially as the temperature rises to a minimum of approx. 60°C and only then increases.

The velocity of sound in water therefore has a positive temperature coeffizient initially and, taking into account the density, which becomes lower as the temperature rises, reaches a maximum value of 1557 m/s at 74°C. Above this temperature the velocity of sound decreases.

When there is a change of spacing Δl between the sound transmitter and the pickup relative to the starting position (relative phase $\Delta\Phi = 0$), the phase of the received signal is shifted relative to the transmitted signal by

$$\Delta\Phi = \frac{\Delta l}{\lambda} \cdot 2\pi . \qquad (2)$$

When the spacing is further changed, the signals come into coincidence again when

$$\Delta l = n \cdot \lambda; \quad n = 1, 2, \ldots \qquad (3)$$

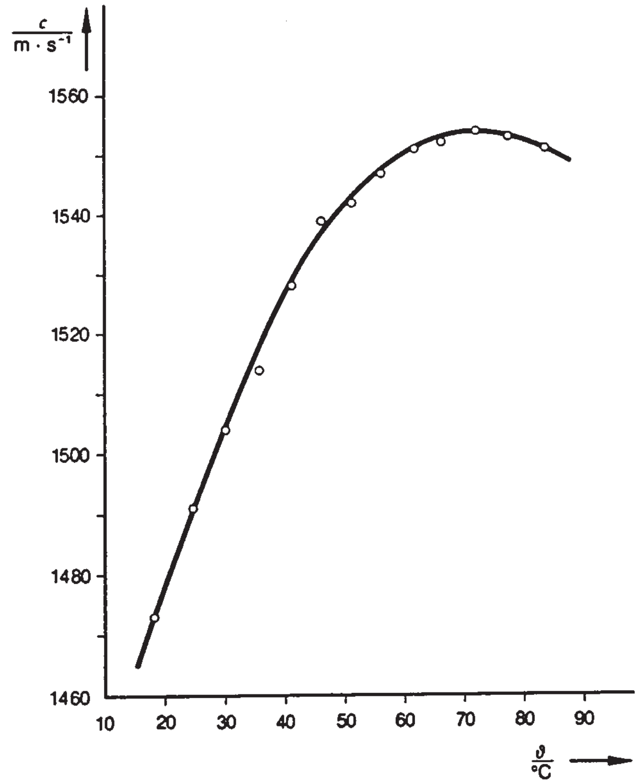
From Eq. (2) and (3) the wavelength can be found to be

$$\lambda = \frac{\Delta l}{\Delta\Phi} \cdot 2\pi = \frac{\Delta l}{n} \cdot \qquad (4)$$

The sound wavelength λ is thus shown to be the slope of the regression straight lines, if the displacement of the detector Δl is plotted as a function of the number n. The phase velocity is obtained with the sound frequency f:

$$c = \lambda \cdot f. \qquad (5)$$

Fig. 2: Velocity of sound in water as a function of the temperature.



In Figs. 2 and 3 the velocities of sound found for water and glycerol in accordance with Eq. (4) and (5) are represented as a function of the liquid temperature.

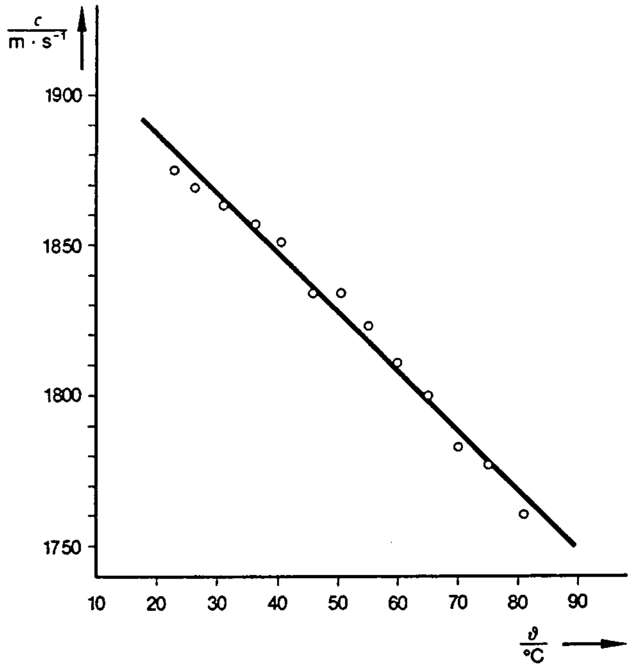
In the measurement example the wavelength of sound for a temperature of the liquid was determined from three separate measurements with the detector moved through 5 wavelengths each time. The error of the mean value is Ac j4 rn/s for water and $\Delta c = \pm 7$ m/s for glycerol.

The measurement example yields a maximum velocity of sound in the case of water of c_{max} = (1554 ± 4) m/s at a liquid temperature of ϑ = 72°C.

Note

The liquid in the region of the acoustic field is heated up by ultrasonic absorption. The measurements should therefore be made with as small a sound amplitude as possible. Attention is also to be paid to thorough mixing of the bath.

Fig. 3: Velocity of sound in glycerol as a function of the temperature.



Velocities of sound with temperature coefficient

Liquid	$\frac{\vartheta}{°C}$	$\frac{c}{m/s}$	$\frac{\Delta c}{\Delta \vartheta}$ / m/s °C	Source
Water	25	1497	+2.5	1)
(dist)	25	1498	+2.4	2)
Glycerol*	20	1923	−1.8	1)
	25	1904	−2.2	2)

* Since glycerol is hygroscopic, a lower velocity of sound is often measured for stale glycerol.

Bibliography

1) L. Bergmann, Der Ultraschall (Hirzel Verlag)

2) Handbook of Chemistry and Physics (The Chemical Rubber Co.)