LEP 1.5.10

Optical determination of velocity of sound in liquids

Related topics

Ultrasonics, sound velocity, ferquency, wavelength, sound pressure, stationary waves.

Principle and task

A stationary ultrasonic wave in a glass cell full of liquid is traversed by a divergent beam of light. The sound wavelength can be determined from the central projection of the sound field on the basis of the refractive index which canges with the sound pressure.

Equipment

Ultrasonic generator	11744.93	1
Laser,He-Ne 1.0 mW, 230 V AC	08181.93	1
Glass cell, 150×55×100 mm	03504.00	1
Lens holder	08012.00	1
Lens, mounted, f +20 mm	08018.01	1
Screen, metal, 300×300 mm	08062.00	1
Optical profile-bench, l 1000 mm	08282.00	1
Base f. opt. profile-bench, adjust.	08284.00	2
Slide mount f. opt. pr.-bench, h 80 mm	08286.02	1
Slide mount f. opt. pr.-bench, h 30 mm	08286.01	3
Swinging arm	08256.00	1
Table top on rod, 18.5×11 cm	08060.00	1
Thermometer -10...+30 C	05949.00	1
Right angle clamp -PASS-	02040.55	1
Support rod, l 250 mm	02021.00	1
Universal clamp	37715.00	1
Glycerol 250 ml	30084.25	3
Water, distilled 5 l	31246.81	1

Problems

To determine the wavelength of sound in liquids, and from this calucate the sound velocity, from the structure of the centrally projected image.

Set-up and procedure

Fig. 1 shows the experiment set-up. The glass cell is 2/3 full of liquid, and the sound head is immersed in it to a depth of a few millimetres, with its face parallel to the bottom of the cell.

The laser beam is enlarged with a lens of focal length +20 mm. The lens is approx. 0–20 cm, the projection screen about 50 cm, away from the cell. The laser and the lens are adjusted so that the beam traverses the liquid between the sound head and the cell bottom.

The experiment is carried out in a semi-darkened room. With the generator amplitude on the medium setting, the depth of immersion of the sound head is so adjusted as to produce a well-defined system of light and dark bands in the projected image.

The distance between the bands is determined for various liquids and the liquid temperature measured in each case.

Any gas bubbles forming on the surface of the sound head and the walls of the cell are removed with a rod.

Fig. 1: Experimental set-up for interference measurements.

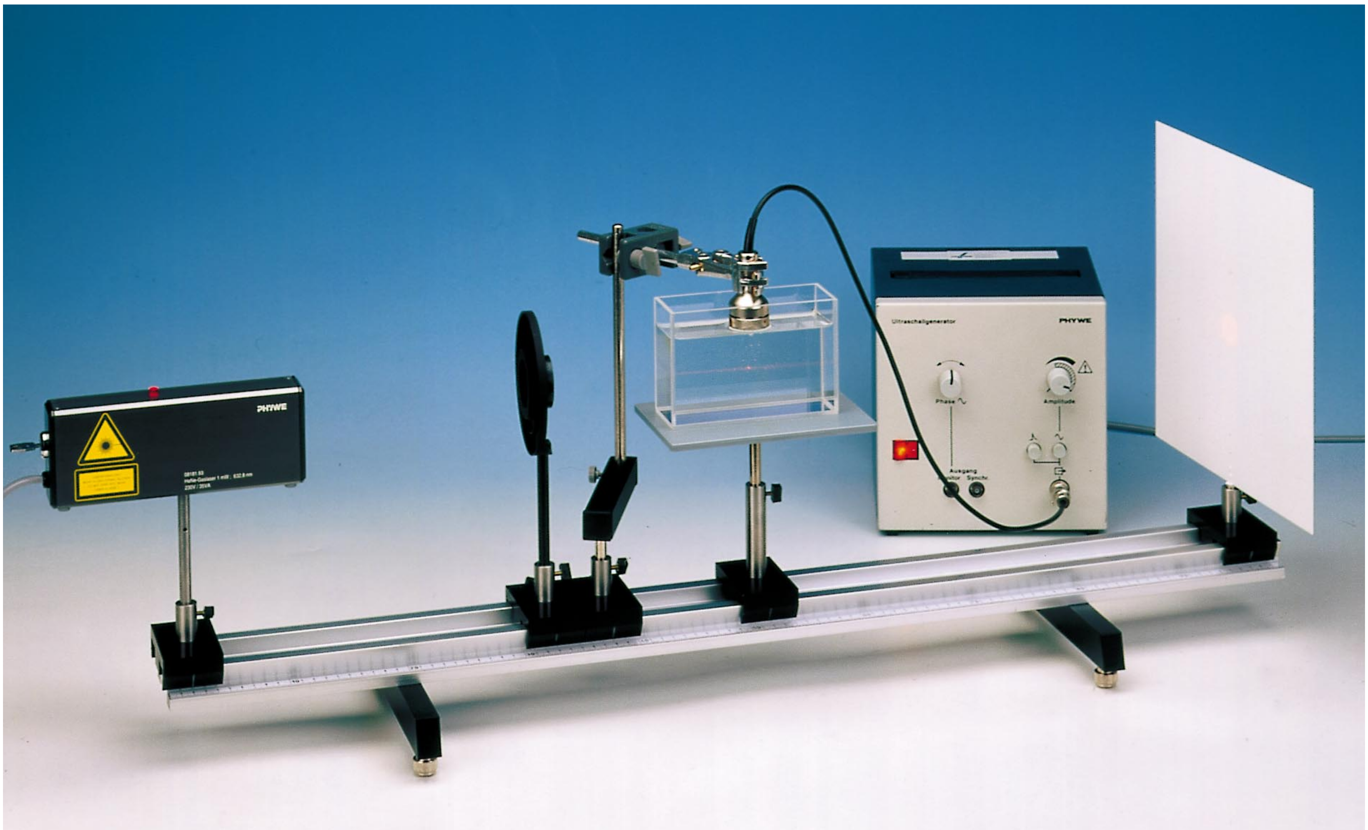
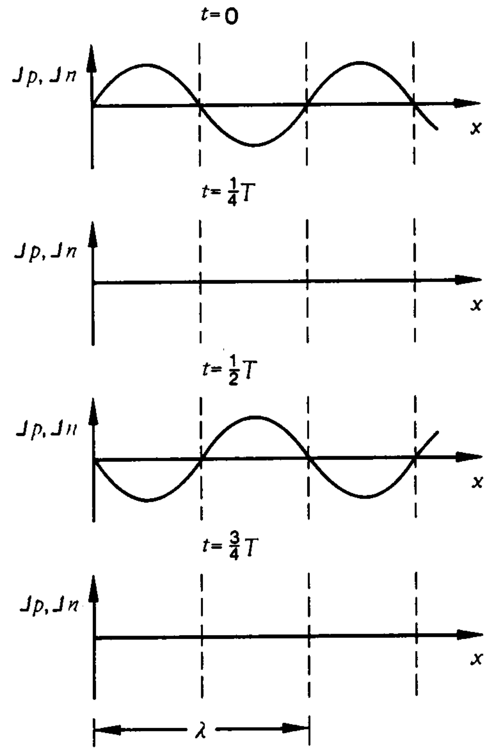


Fig. 2: Localised distribution of the change in pressure or refractive index for four phases of a stationary wave.



Theory and evaluation

Fig. 2 shows the relationship between variations in sound pressure Δp and the location x for four phases of a stationary wave. The refractive index of the liquid also changes because of the pressure variations, and the change in refractive index Δn can be regarded as proportional to the pressure variation Δp.

In phases $t = 0$ and $t = \frac{1}{2}\,T$ (where T is the vibration period), well-defined interference fringes occur, spaced apart by $\lambda/2$.

The light passing through the liquid is deflected into the vibration nodes in the regions where there is a considerable local variation of the refractive index, whereas in the antinode areas it is hardly deflected at all. The vibration nodes thus appear as dark bands and the antinodes as light bands in the central projection.

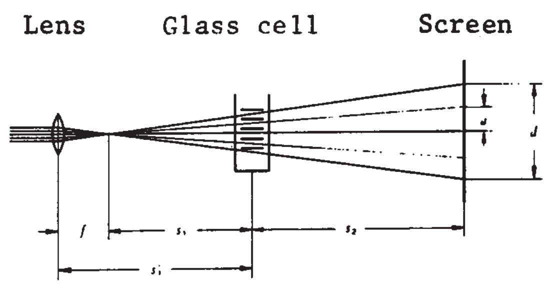


Fig. 3: Path of the rays in the central projection.

Phases $t = \frac{1}{4}\,T$ and $t = \frac{3}{4}\,T$, in which the light passing through the liquid is not deflected, only cause the projected image to lighten.

The spacing of the interference fringes ($\lambda/2$), and therefore the wavelength λ, can be measured from the height d of the projected image and the number N of fringes it contains, using the equation

$$\lambda = 2\alpha \frac{s_1}{s_1 + s_2}$$

where

$$\alpha = \frac{d}{N + 1}$$

as shown by Fig. 3.

The sound propagation velocity is obtained from

$$c = \lambda \cdot f$$

where f is the ultrasonic frequency.

Table 1

Liquid	N	$\frac{d}{mm}$	$\frac{\alpha}{mm}$	$\frac{\lambda}{mm}$	$\frac{c}{m/s}$	$\frac{\Delta c}{m/s}$	$\frac{\vartheta}{°C}$
Glycerol	12	47.5	3.65	2.37	1900	20	25
alcohol (ethanol)	20	48.5	2.31	1.50	1200	12	25
Water (dist.)	19	57.0	2.85	1.85	1480	14	25
Common salt solution (saturated)	17	55.5	3.47	2.25	1800	20	25

Table 1, summarises typical examples of measurements.
The distances are:

$s_1' = 50$ cm
$s_1 = 48$ cm
$s_2 = 148$ cm

$f = 800$ kHz is used as the ultrasonic frequency.

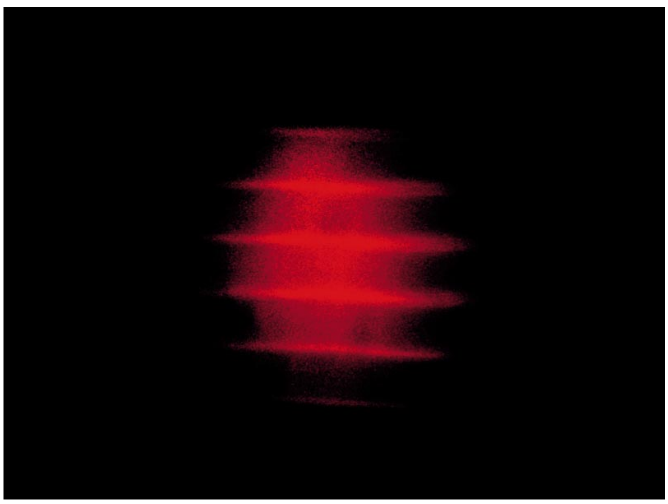


Fig. 4: Image of a screen.

The standard error is caluclated in accordance with the law of error propagation, the individual error values being estimated as:

Δs_1 = 3 mm
Δs_2 = 3 mm
Δd = 0.3 mm
Δf = 5 kHz (see Operating Instructions for the Ultrasonic Generator).

Remark

Relationship between temperature and sound velocity:

Liquid	$\frac{\vartheta}{°C}$	$\frac{c}{m/s}$	$\frac{\frac{\Delta c}{\Delta \vartheta}}{m/s\ °C}$	Source
Glycerol+	20	1923	−1.8	*
	25	1904	−2.2	**
Ethanol	20	1180	−3.6	*
	25	1207	−4	**
Water (Dist).	25	1497	+2.5	*
	25	1498	+2.4	**

+ As glycerol is hygroscopic, smaller values are often found for a glycerol which has been allowed to stand.

Bibliography

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

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