Related topics
Ultrasonics, sound velocity, frequency, 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 changes 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 1
Water, distilled 5 l 31246.81 1

Problems
To determine the wavelength of sound in liquids, and from this calculate 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.

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 \(\lambda\), 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**

<table>
<thead>
<tr>
<th>Liquid</th>
<th>(N)</th>
<th>(\lambda) mm</th>
<th>(\lambda) mm</th>
<th>(c) m/s</th>
<th>(\Delta c) m/s</th>
<th>(\sigma) °</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycerol</td>
<td>12</td>
<td>47.5</td>
<td>3.65</td>
<td>2.37</td>
<td>1900</td>
<td>20 25</td>
</tr>
<tr>
<td>alcohol (ethanol)</td>
<td>20</td>
<td>48.5</td>
<td>2.31</td>
<td>1.50</td>
<td>1200</td>
<td>12 25</td>
</tr>
<tr>
<td>Water (dist.)</td>
<td>19</td>
<td>57.0</td>
<td>2.85</td>
<td>1.85</td>
<td>1480</td>
<td>14 25</td>
</tr>
<tr>
<td>Common salt solution</td>
<td>17</td>
<td>55.5</td>
<td>3.47</td>
<td>2.25</td>
<td>1800</td>
<td>20 25</td>
</tr>
<tr>
<td>(saturated)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

\[ s_1 = 50 \text{ cm} \]
\[ s_1 = 48 \text{ cm} \]
\[ s_2 = 148 \text{ cm} \]

\(f = 800\ \text{kHz}\) is used as the ultrasonic frequency.
The standard error is calculated in accordance with the law of error propagation, the individual error values being estimated as:

\[ \Delta s_1 = 3 \text{ mm} \]
\[ \Delta s_2 = 3 \text{ mm} \]
\[ \Delta d = 0.3 \text{ mm} \]
\[ \Delta f = 5 \text{ kHz} \] (see Operating Instructions for the Ultrasonic Generator).

**Remark**

Relationship between temperature and sound velocity:

<table>
<thead>
<tr>
<th>Liquid</th>
<th>( \theta ) °C</th>
<th>( c ) m/s</th>
<th>( \frac{\Delta c}{\Delta \theta} ) m/s °C</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycerol*</td>
<td>20</td>
<td>1923</td>
<td>-1.8</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>1904</td>
<td>-2.2</td>
<td>**</td>
</tr>
<tr>
<td>Ethanol</td>
<td>20 1923</td>
<td>1904</td>
<td>-2.2</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>1207</td>
<td>-4</td>
<td>**</td>
</tr>
<tr>
<td>Water (Dist.)</td>
<td>25</td>
<td>1497</td>
<td>2.5</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>1498</td>
<td>2.4</td>
<td>**</td>
</tr>
</tbody>
</table>

* 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.