**Experiment-165 S**

# VELOCITY OF SOUND IN LIQUIDS

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***Abstract***

***Velocity of sound in Carbon Tetra Chloride ($CCl_4$), Drinking water and Kerosene is determined using ultrasonic interferometer consisting of aqua grating and ultra sound transmitter. The angular separation is measured using a spectrometer and a monochromatic light is used to illuminate the aqua grating.***

## Introduction

Sound is produced by mechanical vibration and it requires a medium to travel. In a lighter medium it travels faster and in denser medium it travels slower [1, 2]. Air is a denser medium compared to water hence sound travels slower in air than in water. Depending on the density of the medium and its bulk modulus the sound velocity varies. The velocity of sound is given by

$$V = \sqrt{\frac{k}{\rho}} \qquad \ldots 1$$

Where V is the velocity of sound
$\rho$ is the density of the medium
k is the bulk modulus of the medium

It is difficult to determine bulk modulus of liquid compared to solids. Hence to determine sound velocity in various liquid media, interference method is used. Further with the highest frequency (20 KHz) audible sound the interference pattern formed will be very close practically merging with 0.08 minute angular separation between fringes, which can not be measured using regular spectrometers with least count of 1 minute or 0.5 minute. Hence one has to use high frequency sound waves or ultra sound to form interference fringes with measurable angular separation of the order 10 to 20 minutes. Using ultra sound in the MHz region it is possible to view well defined fringes with measurable angular separations.

When sound travels in a liquid medium molecules of the liquid start vibrating perpendicular to the direction of wave propagation. Depending on the density and its bulk modulus the amplitude and frequency of vibration will change. Hence the velocity of sound is different for different liquids. Table-1 gives the velocity of ultrasound in common liquids. The velocity of sound in liquid is given by eaquation-1. Velocity of sound varies from 1540 m/sec in soft tissue to 4050m/sec in human skull bone [3]. This large range of variation made ultrasound as one of important probe to diagnose human body.

**Table-1**

| Liquid | Velocity (m/sec) | Liquid | Velocity (m/sec) |
|---|---|---|---|
| Distilled Water | 1498 | Glycerol | 1904 |
| Sea water | 1533 | Chloroform | 987 |
| $CCl_4$ | 926 | Turpentine | 1255 |
| Benzene | 1295 | Castor oil | 1477 |
| Acetone | 1174 | Kerosene | 1324 |

***Velocity of sound in popular liquids***

## Aqua Grating

A rectangular 7.6 x 5.1 x 5.1 $cm^3$ (3 x 2 x 2 x $inch^3$) glass vessel made by joining optically plane glass plates is shown in Figure-1(a). The glass vessel is illuminated by a monochromatic light perpendicular to its length. A quartz crystal (4MHz) is placed inside the vessel immersed in organic liquid or water. The crystal is excited by high frequency (1-10MHz) high voltage (250V) sine wave. When the input sine wave frequency becomes equals to the crystal frequency, maximum power is transferred from the source to the crystal. The crystal converts the electrical signal into ultra sound and sound waves start moving in the liquid along the length of the glass vessel as shown in Figure -2. The ultrasound wave gets reflected back from the opposite side of the glass vessel and a standing wave pattern is formed. The standing wave pattern, liquid, glass vessel form the aqua grating. The aqua grating is mounted on the prism table as shown in Figuire-1(b) between the telescope and the collimator of the spectrometer.

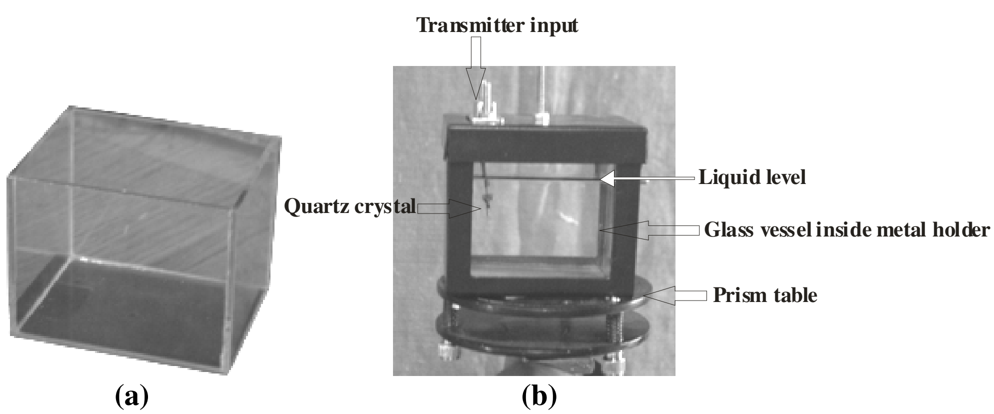



**Figure-1: (a) Glass vessel 3x2x2 made by joining optically plane glass plates (b) aqua grating**

The trough (node) the crest (antinode) of the standing wave acts like transparent and opaque regions for the incident light. The incident light passes through the trough region and is blocked by the crest region of the standing wave. In between the trough and the crest the light passes through with varying intensities. In effect, the trough acts like un-ruled region of the grating and crest acts like ruled region of the grating. Hence the same equation governing the diffraction grating is true in this case also. Figures- 3&4 show the regions of the standing wave from where light gets transmitted and blocked.

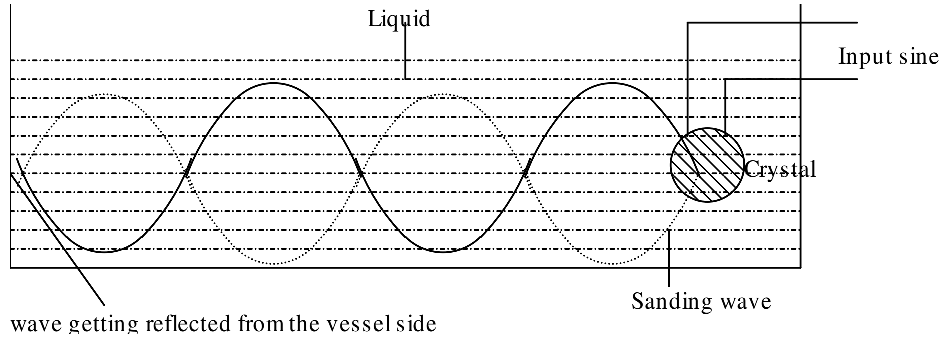
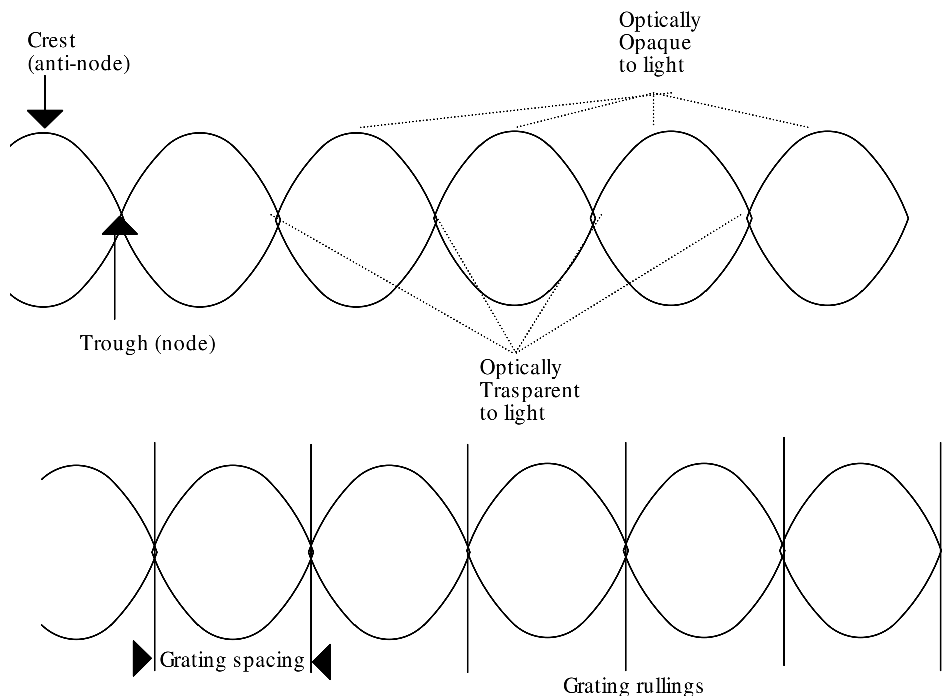



**Figure-2: Generation of ultra sound and its propagation forming standing wave.**




$$d = \frac{\lambda'}{2}$$

**Figure-3: The transparent and opaque regions of the standing wave**

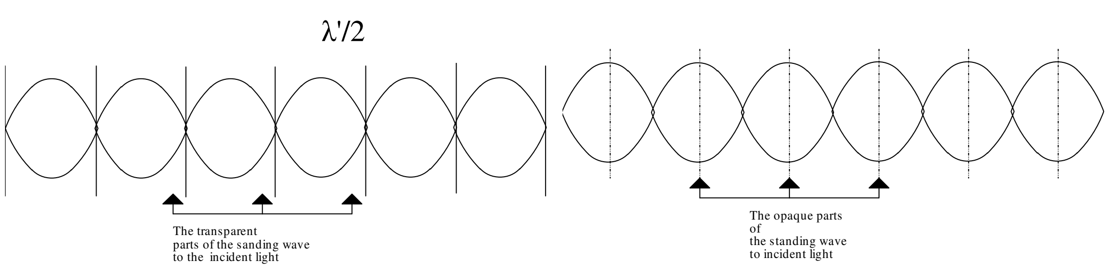



**Figure-4, Standing wave acting like grating**

$$2d \sin\theta = n\lambda \qquad \ldots 2$$

Where d is the grating constant or grating spacing
$\theta$ is angle of diffraction

n is order of the spectrum
$\lambda$ is wavelength of the incident light

If $\lambda'$ is the wavelength of the standing wave formed then the distance between two consecutive troughs or two consecutive crests is $\lambda'/2$. Or in other words the grating spacing, d, is given by

$$d = \frac{\lambda'}{2} \quad \ldots 3$$

Substituting for d in equation-2

$$2\frac{\lambda'}{2}\sin\theta = n\lambda$$

$$\lambda' = \frac{n\lambda}{\sin\theta} \quad \ldots 4$$

By measuring diffraction angle $\theta$ the wave length of the ultrasound can be determined using this equation.

The velocity of the ultrasound is given by

$$V = f\lambda' \quad \ldots 5$$

where V is the velocity of the ultrasound in liquid
f is frequency of the ultra sound wave
$\lambda'$ is the wave length of ultra sound wave.

Since frequency of the sound wave is known, its velocity can be determined.

## Measurement of angle of diffraction θ

By measuring the angular separation between respective order spectra or fringes the diffraction angle $\theta$ can be evaluated. The angular separation between first order fringes is given by

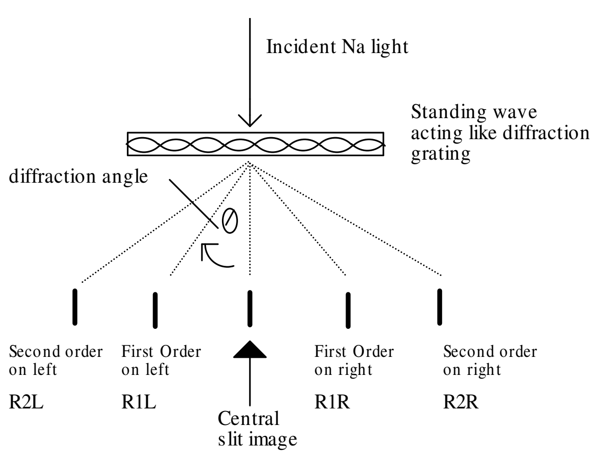



**Figure-5: Formation of spectrum by aqua grating**

$$2\theta_1 = R_{1L} - R_{1R} \quad \ldots 6$$

Where $\theta_1$ is angle of diffraction angle for the first order
$R_{IL}$ is spectrometer reading corresponding to first order line on left.
$R_{IR}$ is spectrometer reading corresponding to first order line on right.
.

Similarly for the second order spectra angular separation is given by

$$2\theta_2 = R_{2L} - R_{2R} \qquad \ldots 7$$

In general for the $n^{th}$ order spectrum the angular separation is given by

$$2\theta_n = R_{nL} - R_{nR} \qquad \ldots 8$$

Where $\theta_n$ is angle diffraction for the $n^{th}$ order
$R_{nL}$ is spectrometer reading corresponding to $n^{th}$ order line on left.
$R_{nR}$ is spectrometer reading corresponding to $n^{th}$ order line on right.

## Apparatus used

Ultrasonic interferometer consisting of a 6 inch spectrometer, aqua grating, a quartz crystal and high voltage high frequency sine wave transmitter and sodium vapor light.

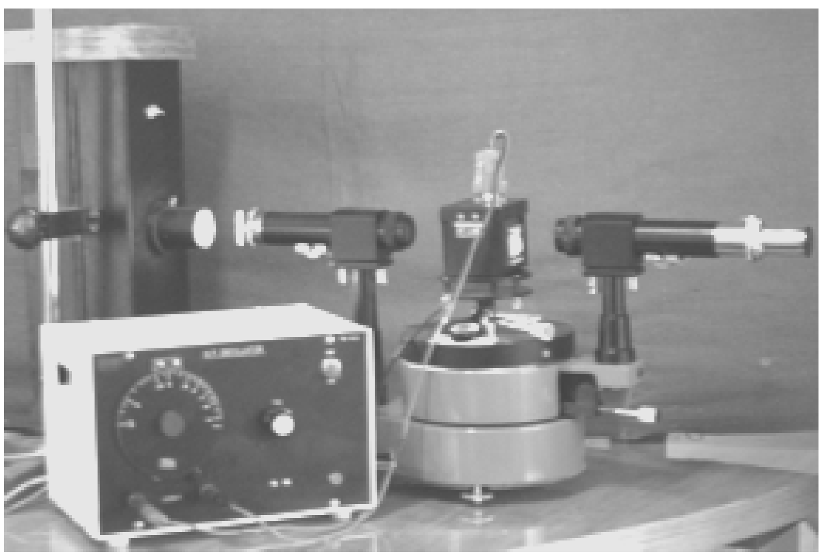


**Figure-6: Ultrasonic interferometer**

## Liquids Used

Carbon tetra chloride, kerosene and drinking water

## Experimental Procedure

The complete experimental setup used in the experiment is shown in Figure-6.

1. The spectrometer is placed in front of a white wall near a window and the eye piece is pulled or pushed such that the cross wire is distinctly seen and adjusted to its vertical position.

2. The spectrometer is now taken out of the dark room and its telescope is adjusted by focusing on to a distant building (more than 100 meters away) and the telescope is adjusted to catch the distant image very clearly.

3. The spectrometer is now placed in front of a sodium vapor lamp, the slit is illuminated and the collimator is adjusted to set the clear slit image.

4. The telescope is brought in line with the collimator, and the slit image is seen through the backdrop of cross wire.

5. The aqua grating fitted to the prism table is now filled with carbon tetra chloride and quartz crystal is immersed in the liquid with its plane perpendicular to the incident light through the collimator.

6. The transmitter output is connected to the crystal using D-type connector provided along with the experimental setup. The frequency knob of the sine wave transmitter is adjusted viewing through the telescope until the slit images split to give number of fine lines as shown in Figure-7 and the frequency of the input sine wave is noted from the dial

   f = 4MHz

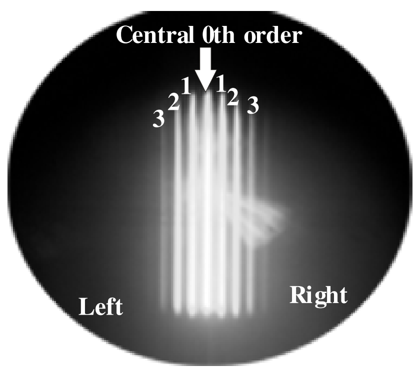



**Figure-7: Spectral lines observed for $CCl_4$**

7. The central slit image, first order spectral line on left ($R_{1L}$), first order spectral line on the right ($R_{1R}$), second order spectral line on the left ($R_{2L}$), second order spectral line on the right ($R_{2R}$) are identified in the observed spectrum as shown in Figure-5.

8. The vertical cross wire is now made to coincide with second order spectral line on the left ($R_{2L}$) as shown in Figure-5 and spectrometer reading corresponding to this position is noted as in Table-2.

   $R_{2L} = 81^\circ\, 24' = 81.4^\circ$

9. The vertical cross wire is now made to coincide with the second order spectral line on the right and the spectrometer reading noted at this position.

   $R_{2R} = 82^o\ 0'$

   The angular separation for the second order spectral line, calculated using equation-7, is given by

   $2\theta_2 = R_{2R} - R_{2L} = 82^o - 81.4^o$

   $2\theta_2 = 0.60^o$ or the second order diffraction angle

   $\theta_2 = 0.30^o$

10. Wave length of the ultrasonic calculated using equation-4

    $$\lambda' = \frac{n\lambda}{\sin\theta} = \frac{2x589X10^{-9}}{Sin(0.3)} = \frac{1.178X10^{-6}}{5.236X10^{-3}} = 2.249x10^{-4}\ m.$$

    Velocity of ultrasound is calculated using equation-5

    $V = f\ \lambda' = 4x10^6\ x2.249x10^{-4} = 899.92m/sec.$

11. Similarly the angular separation between the first order spectral line is determined by coinciding the vertical to first order spectral line ($R_{1L}$) on the left. And spectrometer reading is noted in Table-2.

    $R_{IL} = 81.5^o\ \ 20' = 81.83^o$

12. The vertical cross wire is now coincided with first order spectral line ($R_{1R}$) on the right and spectrometer reading is noted in Table-2 and angular separation for first order spectral line is calculated.

    $R_{IR} = 81.5^o\ \ 5' = 81.58^o$

    Angular separation for first order spectral line

    $2\theta_1 = R_{IL} - R_{IR} = 81.83-81.58 = 0.25^o$

    $2\theta_1 = 0.25^o$

    $\theta_1 = 0.125^o$

13. Wave length is calculated using eaquation-4

    $$\lambda' = \frac{n\lambda}{Sin\theta} = \frac{1x589X10^{-9}}{Sin0.125} = 2.699x10^{-4}\ m$$

    Velocity of ultrasound is calculated using equation-5

    $V = f\ \lambda' = 1079m/sec.$

Average velocity is calculated

899.92 +1079.91 = 990m/sec

14. Experiment is repeated for drinking water and kerosene and the corresponding readings obtained are tabulated in Table- 2

**Table-2**

| Liquid | Spectral Order | Spectrometer reading | | Angular separation $2\theta_n^o$ | Angle of diffraction $\theta_n^o$ | Wavelength $\lambda x10^{-4}$(m) | Ultra sound Velocity (m/sec) |
|---|---|---|---|---|---|---|---|
| | | $R_{nL}^o$ | $R_{nR}^o$ | | | | |
| $CCl_4$ | 2 | 82 | 81.4 | 0.6 | 0.300 | 2.249 | 900 |
| | 1 | 81.58 | 81.83 | 0.25 | 0.125 | 2.699 | 1079 |
| $H_2O$ | 1 | 81.63 | 81.80 | 0.17 | 0.085 | 3.970 | 1588 |
| Kerosene | 2 | 81.91 | 81.50 | 0.41 | 0.205 | 3.292 | 1316 |
| | 1 | 81.58 | 81.83 | 0.253 | 0.126 | 2.660 | 1067 |

***Angular separation, angle of diffraction and Ultrasound velocity***

## Results

The result obtained are tabulated in Table-3

**Table-3**

| Liquid | Velocity of sound (m/sec) | |
|---|---|---|
| | Expt. | Standard |
| $CCl_4$ | 990 | 926 |
| $H_2O$ | 1588 | 1493 |
| Kerosene | 1191 | 1324 |

***Experimental results***

## Discussions

This is an important experiment to understand the wave nature and its wave effect. Sound wave forms a standing wave pattern through which light of smaller wavelength wave passes through producing interference pattern which can be observed using a spectrometer. However, the standing wave formed can not be viewed, only its effect is observed.

## References

[1] Chauhan M S and Singh S P, Advanced Practical Physics Vol-1, Page-18.

[2] Optical Determination of velocity of sound in liquids, PHYWE series publication

[3] Beverly Stern, The basic concepts of ultrasound, www. yale.edu/ynhti/curriculum/units

PHYWE

# Optical determination of velocity of sound in liquids

LEP 1.5.10 -00

## Related topics

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

## Principle

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 | 02031.00 | 1 |
| Universal clamp | 37715.00 | 1 |
| Glycerol, 250 ml | 30084.25 | 3 |
| Water, distilled, 5 l | 31246.81 | 1 |

## Tasks

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.

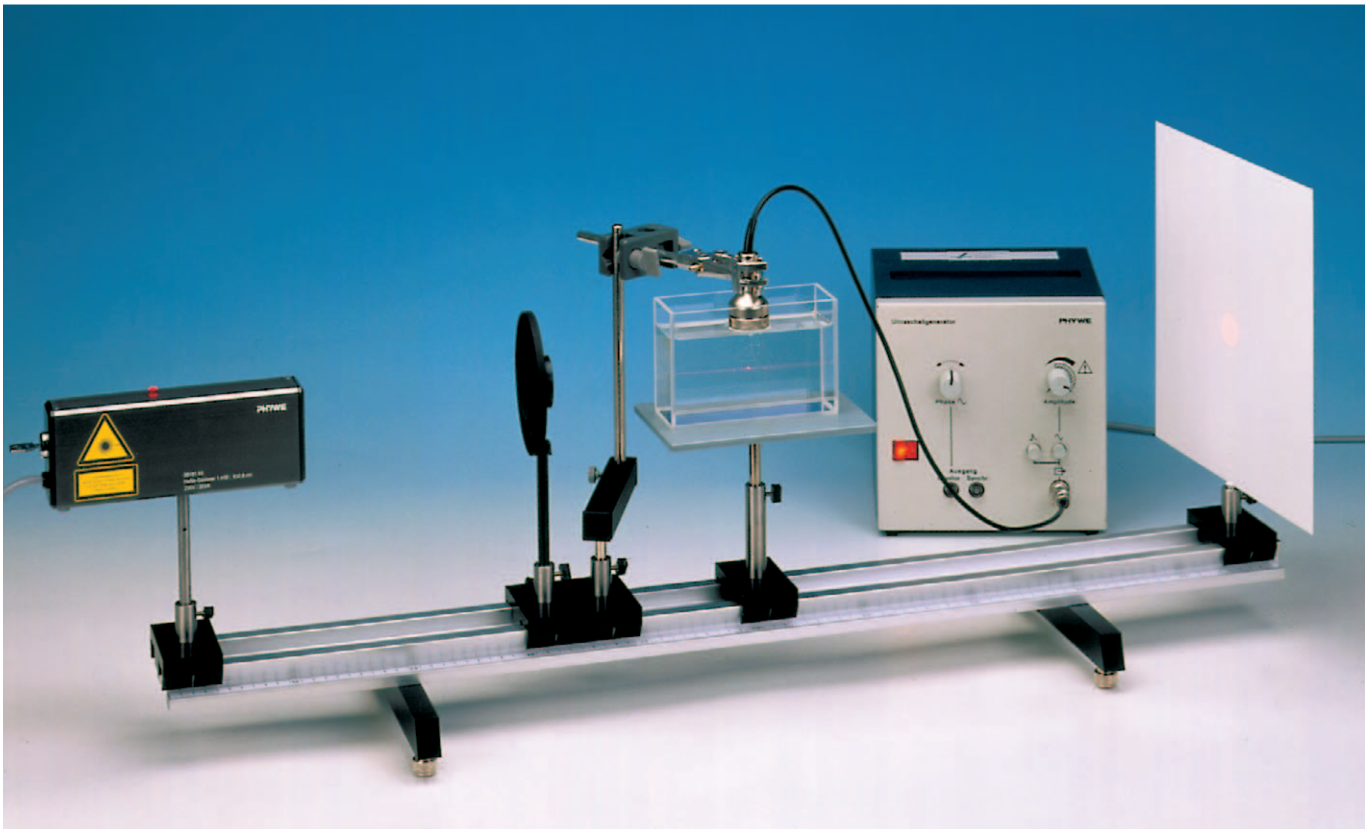
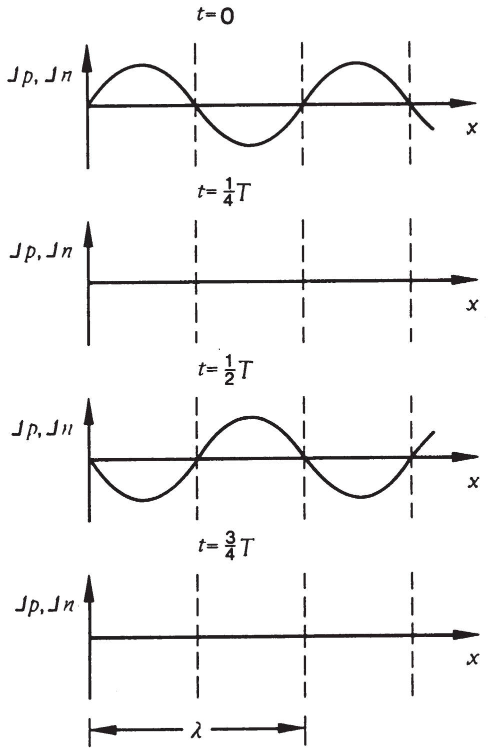


Fig. 2: Localised distribution of the change in pressure or refractive index for four phases of a stationary wave.




**Theory and evaluation**

Fig. 2 shows the relationship between variations in sound pressure $\Delta p$ 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 $\Delta n$ can be regarded as proportional to the pressure variation $\Delta p$.

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

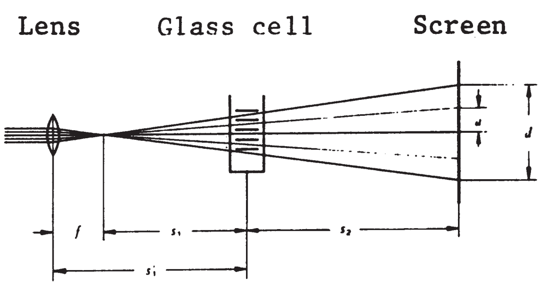



Fig. 3: Path of the rays in the central projection.

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 (λ/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 | $N$ | $\frac{d}{\text{mm}}$ | $\frac{\alpha}{\text{mm}}$ | $\frac{\lambda}{\text{mm}}$ | $\frac{c}{\text{m/s}}$ | $\frac{\Delta c}{\text{m/s}}$ | $\frac{\vartheta}{°\text{C}}$ |
|---|---|---|---|---|---|---|---|
| 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.

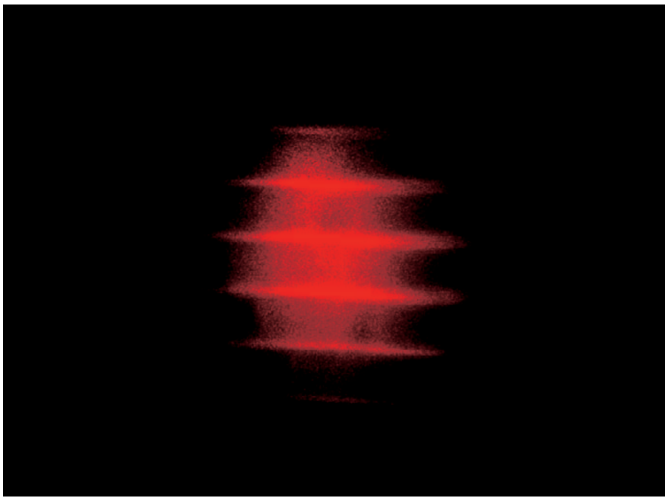


Fig. 4: Image of a screen.

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

$\Delta s_1$ = 3 mm
$\Delta s_2$ = 3 mm
$\Delta d$ = 0.3 mm
$\Delta f$ = 5 kHz (see Operating Instructions for the Ultrasonic Generator).

**Remark**

Relationship between temperature and sound velocity:

| Liquid | $\frac{\vartheta}{°C}$ | $\frac{c}{m/s}$ | $\frac{\Delta c / \Delta \vartheta}{m/s\ °C}$ | 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.