

Debye-Sears Effect

DETERMINE THE VELOCITY OF ULTRASONIC WAVES IN LIQUIDS.

- Observing the diffraction pattern at a fixed ultrasound frequency for two different light wavelengths.
- Observing the diffraction pattern for different ultrasound frequencies between 1 MHz and 12 MHz.
- Determining the corresponding sound wavelengths and the velocity of sound.

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BASIC PRINCIPLES

The diffraction of light by ultrasonic waves in liquids was predicted by *Brillouin* in 1922, and the effect was confirmed experimentally in 1932 by *Debye* and *Sears* and also by *Lucas* and *Biquard*. It is caused by the periodic variations in the refractive index of the liquid that are produced by ultrasonic waves. If a light beam is passed through the liquid perpendicular to the ultrasound direction, the arrangement acts as a phase grating, which moves depending on the velocity of sound. Its grating constant corresponds to the wavelength of the ultrasound, and thus depends on its frequency and the velocity of sound in the medium. The movement of the phase grating can be neglected if the effect is observed on a screen at a large distance.

In the experiment, a vertically orientated generator couples ultrasonic waves at frequencies between 1 MHz and 12 MHz into the test liquid. A monochromatic parallel light beam passes through the liquid in the horizontal direction and is diffracted by the phase grating (see fig. 1). The diffraction pattern contains several diffraction maxima spaced at regular distances (see fig. 2).

The k th-order maximum of the diffraction pattern is found at the diffraction angle α_k , defined by

$$(1) \quad \tan \alpha_k = k \cdot \frac{\lambda_L}{\lambda_S}$$

λ_L : light wavelength, λ_S : ultrasound wavelength.

Thus, the ultrasound wavelength λ_S can be determined from the separation between the diffraction maxima. Furthermore, according to the relationship

$$(2) \quad c = f \cdot \lambda_S$$

it is possible to calculate the velocity of sound c in the liquid, since the frequency f of the ultrasonic waves is also known.

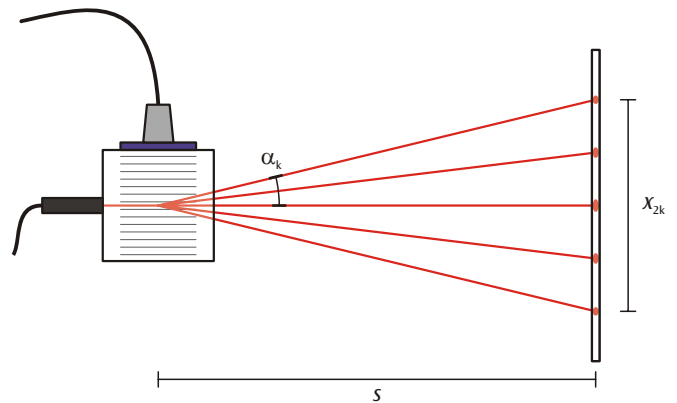


Fig. 1: Diagram showing the diffraction of light by a phase grating that is produced in a liquid by ultrasonic waves

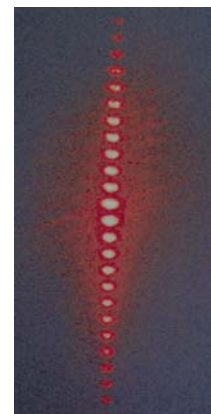


Fig. 2: Diffraction pattern caused by the diffraction of light at a phase grating produced in a liquid by ultrasonic waves

LIST OF APPARATUS

1	Ultrasonic cw Generator	U100061
1	Test Vessel	U10008
1	Laser Diode for Debye-Sears Effect, Red	U10007
1	Laser Diode for Debye-Sears Effect, Green	U10009
1	Pocket Measuring Tape, 2 m	U10073
1	Ultrasonic Coupling Gel	XP999

SET-UP

- Fill the test vessel with distilled water and place it about 3 m from the projection screen.
- Mount the multi-frequency probe vertically in the holder of the test vessel and connect it to the PROBE output of the ultrasonic generator (see Fig. 3).
- Mount the red laser diode in the laser holder of the test vessel and connect it to the LASER output of the ultrasonic generator.



Fig. 3: Experiment set-up for the diffraction of light at a phase grating produced in a liquid by ultrasonic waves

EXPERIMENT PROCEDURE

- Measure the distance s between the multi-frequency probe and the screen.
- Switch on the ultrasonic cw generator.
- Switch on the laser and the multi-frequency probe.
- Set the frequency to 1 MHz.
- Adjust the amplitude of the transducer signal, and by means of the three adjusting screws of the transducer holder adjust the orientation of the multi-frequency probe so that standing waves are generated.
- On the screen measure the distance x_{2k} between the $-k$ th order and the $+k$ th order diffraction maxima.
- Increase the frequency in steps of 1 MHz up to 12 MHz, and for each frequency measure the distance x_{2k} and determine the diffraction order k .
- Replace the red laser diode with a green one and make a similar set of measurements.

SAMPLE MEASUREMENTS AND EVALUATION

$s = 325$ cm

Table 1: Experiment data with light of wavelength $\lambda_L = 652$ nm (red laser)

f / MHz	k	x_{2k} / cm	λ_S / μm
1	9	2.5	1525.7
2	5	2.8	756.8
3	5	4.3	492.8
4	3	3.5	363.3
5	3	4.3	295.7
6	2	3.5	242.2
7	2	4.0	211.9
8	2	4.6	184.3
9	2	5.2	163.0
10	1	2.8	151.4
11	1	3.2	132.4
12	1	3.5	121.1

Table 2: Experiment data with light of wavelength $\lambda_L = 532$ nm (green laser)

f / MHz	k	x_{2k} / cm	λ_S / μm
2	5	2.4	720.4
3	4	2.9	477.0
4	3	2.8	370.5
5	2	2.3	300.7
6	2	2.8	247.0
7	2	3.2	216.1
8	2	3.7	186.9
9	2	4.2	164.7
10	2	4.6	150.3
11	1	2.6	133.0
12	1	2.8	123.5

It is necessary to measure the distance s between the ultrasound generator and the screen used to observe the diffraction pattern, and the distance x_{2k} between the $-k$ th and the $+k$ th diffraction maxima. From these two distances, it is possible to calculate the diffraction angle α_k for the k th-order maximum, given by:

$$\tan \alpha_k = \frac{x_{2k}}{2 \cdot s}$$

This leads to the following equation for determining the ultrasound wavelength λ_S :

$$\lambda_S = \frac{2 \cdot k \cdot s}{x_{2k}} \cdot \lambda_L$$

This is the equation by which the sound wavelengths in the right-hand column of both tables were calculated.

Figure 4 shows the calculated sound wavelength as a function of the frequency of the ultrasonic waves. The hyperbola curve was calculated according to Equation (2) as:

$$\lambda_s = \frac{c}{f} \text{ with } c = 1482 \frac{\text{m}}{\text{s}}$$

The velocity of sound c determined by this curve-fitting procedure is in excellent agreement with the literature value.

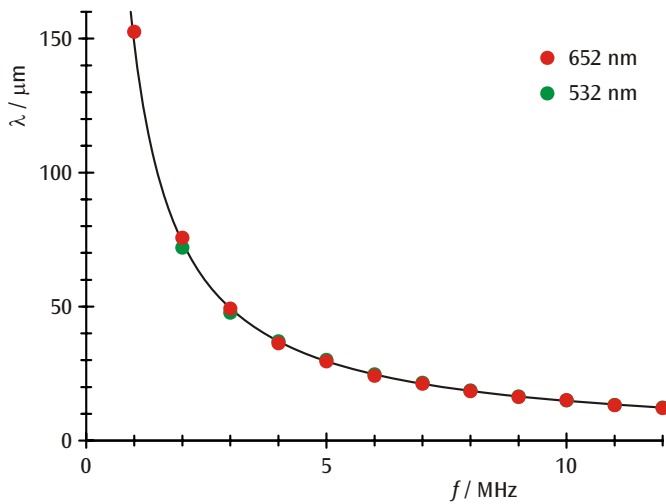


Fig. 4: Sound wavelength λ_s in water as a function of the frequency f

