Principles

Relationships which are true for all waves can be demonstrated particularly clearly using water waves, as here the phenomena can be observed with the naked eye, and can be considered as occurring in a two-dimensional manner. Thus, it is easy to illustrate and explain fundamental concepts of wave propagation such as wave front, direction of propagation, wave packet, energy transport, wave velocity and velocity of propagation, straight or planar waves and circular or spherical waves.

The water waves are generated in a wave trough filled with water; the bottom of the trough consists of a glass pane. To generate waves, the oscillations of a membrane, which are generated in the supply unit by variations in air pressure, are transmitted to the surface of the water via wave exciters. If the beam from a point-type lamp is shone through the wave trough, the wave crests act as collecting lenses to create bright lines on the observation screen; the wave troughs act as dispersing lenses to cause dark lines. To display a stationary wave image, a stroboscopic lamp is synchronized with the frequency generator for the exciter membrane.

Objects of the experiment

- Excitation of circular water waves with the point-type wave exciter.
- Excitation of straight water waves with the exciter for straight waves.
- Observing the water motion in a wave and comparison with the propagation of the wave.
- Measuring the wavelength $\lambda$ of a water wave for various excitation frequencies $f$ and calculating the wave velocity $v$.
- Measuring the propagation velocity $v_{gr}$ of a wave packet.

Fig. 1 Propagation of water waves (photographs)
Top: circular waves
Bottom: straight waves
Setup

Set up the experiment as shown in Fig. 2.

- Set up the wave trough so that it is not subject to shocks and vibrations; observe all information given in the Instruction Sheet.

Carrying out the experiment

a) Generating circular waves:

- Connect a point-type exciter for circular waves as shown in Fig. 3.
- Using knob (e), set a frequency of approx. 20 Hz, and carefully increase the excitation amplitude using knob (d) until wave fronts are clearly visible (see Instruction Sheet for wave trough).
- If necessary, rotate the stroboscope disk out of the beam path using knurled screw (f) so that the glass pane in the bottom of the wave trough is completely illuminated.
- Vary the immersion depth as necessary with adjusting screw (h1).
- To observe stationary wave images, switch on the stroboscope with switch (a); after a short warm-up time, you may need to carry out a fine adjustment of the excitation and stroboscope frequencies using knob (b) until a stationary wave image appears.
- Set different excitation frequencies between 10 Hz and 80 Hz and observe the wave images. Readjust the synchronization and amplitude each time as necessary.

b) Generating straight waves:

- Connect the exciter for straight waves as shown in Fig. 4.
- Using knob (e), set a frequency of approx. 20 Hz, and carefully increase the excitation amplitude until wave fronts are clearly visible (see Instruction Sheet for wave trough).
- If necessary, rotate the stroboscope disk out of the beam path using knurled screw (f) so that the glass pane in the bottom of the wave trough is completely illuminated.
- Vary the immersion depth as necessary with adjusting screw (h2).
- To observe stationary wave images, switch on the stroboscope with switch (a); after a short warm-up time, you may need to carry out a fine adjustment of the excitation and stroboscope frequencies until a stationary wave image appears.
- Set different excitation frequencies between 10 Hz and 80 Hz and observe the wave images. If necessary, readjust the synchronization and amplitude each time.

Apparatus

1 Wave trough with motor stroboscope . . . 401 501
1 Stopclock ............... e.g. 311 031
1 Ruler or tape measure ............... e.g. 311 77

additionally required:
Dish soap,
millimeter-sized Styrofoam balls or scraps of paper

Measuring example and evaluation

Fig. 1 shows two photographs with measurement examples.

Table 1: Wavelength $\lambda$ and wave velocity $v$ of water waves as a function of excitation frequency $f$

<table>
<thead>
<tr>
<th>$f$ (Hz)</th>
<th>$\lambda$ (cm)</th>
<th>$v$ (cm s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2.1</td>
<td>21</td>
</tr>
<tr>
<td>20</td>
<td>1.1</td>
<td>22</td>
</tr>
<tr>
<td>30</td>
<td>0.8</td>
<td>24</td>
</tr>
<tr>
<td>40</td>
<td>0.6</td>
<td>24</td>
</tr>
<tr>
<td>50</td>
<td>0.4</td>
<td>20</td>
</tr>
<tr>
<td>60</td>
<td>0.4</td>
<td>24</td>
</tr>
<tr>
<td>70</td>
<td>0.3</td>
<td>21</td>
</tr>
<tr>
<td>80</td>
<td>0.3</td>
<td>24</td>
</tr>
</tbody>
</table>

Table 2: Propagation velocity of a wave packet

<table>
<thead>
<tr>
<th>$s$ (cm)</th>
<th>$t$ (s)</th>
<th>$v_{gr}$ (cm s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1</td>
<td>20</td>
</tr>
</tbody>
</table>
Waves generated with a point-type exciter propagate radially in circular wave fronts.

Waves which are generated with a straight exciter propagate in a straight line; the wave fronts are perpendicular to the direction of propagation.

The amplitude decreases continuously due to attenuation. The wave image loses contrast as the distance from the exciter increases.

In wave propagation, the water is not transported; it is only made to oscillate. The energy of the oscillation is transported.

In the frequency range between 10-80 Hz the wavelength decreases as the frequency increases.

Within the given measuring accuracy, the propagation velocity \( v_{gr} \) of a wave packet here agrees with the wave propagation velocity calculated from the frequency and wavelength.

Additional information

In the case of water waves, the recoiling force on an oscillating (or better, orbiting) water particle is determined by its weight and by the surface tension. The wave (or phase) velocity \( v \) is a function of the wavelength \( \lambda \):

\[
v = \sqrt{\frac{g \lambda}{2\pi} + \frac{\sigma}{\rho} \frac{2\pi}{\lambda}}
\]

(\( g \): gravitational acceleration, \( \sigma \): surface tension, \( \rho \): density)

Above \( \lambda = 1.7 \) cm, the proportion due to weight predominates, and we speak of “gravity waves”. Here, the wave velocity increases with the wavelength. Below \( \lambda = 1.7 \) cm, the surface tension predominates, and we speak of “ripples”. Here, the wave velocity decreases with the wavelength.

Due to the dispersion described above, the phase velocity \( v \) and the group (or propagation) velocity \( v_{gr} \) differ. However, in the range around \( \lambda = 1.7 \) studied here, the dispersion is so slight that we can assume the phase and group velocities as being approximately equal.

Strictly speaking, equation (I) applies only for water of a sufficient depth. In shallow water with the depth \( h \) the velocity of the gravity waves is

\[
v = \sqrt{\frac{g \lambda}{2\pi} + \frac{2\pi h}{\lambda} \tanh \left( \frac{2\pi h}{\lambda} \right)}
\]

(II)