Generating circular and straight water waves

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 λ 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.

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.

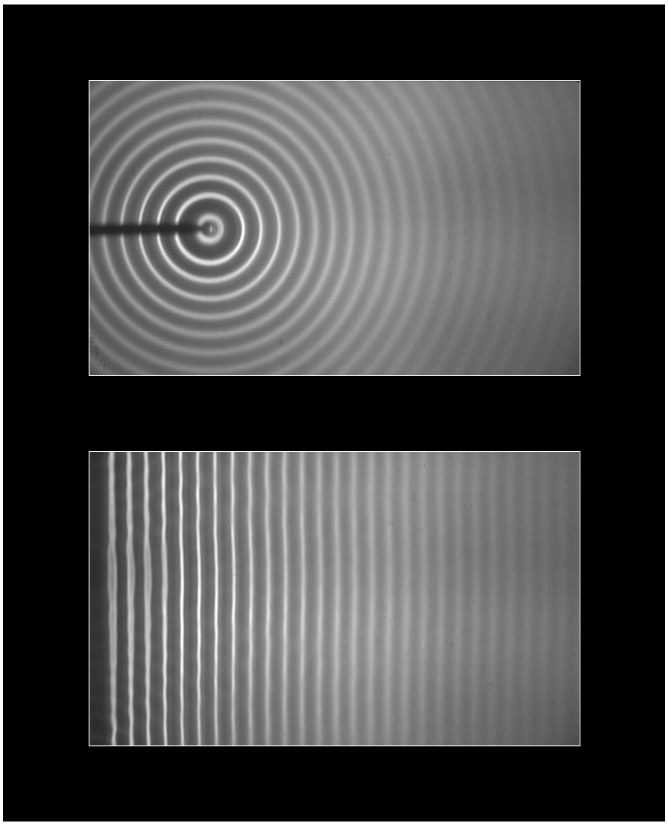

Fig. 1 Propagation of water waves (photographs)
Top: circular waves
Bottom: straight waves

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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

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 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; 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.

c) Observing the motion of water in a wave and comparison with the propagation of the wave:

– Switch off the stroboscope; if necessary, rotate the stroboscope disk out of the beam path.

– Drop in a few Styrofoam balls or scraps of paper at different excitation frequencies, observe their position and compare this with the propagation of the wave.

d) Measuring the wavelength λ for various excitation frequencies *f* and calculating the wave velocity *v*:

– Switch on the stroboscope and generate a stationary wave image by synchronizing the system.

– Measure the distance between two wave fronts on the observation screen **(g)**. Be sure to take the image scale into consideration to determine the actual wavelength (see Instruction Sheet for wave trough).

– Set different excitation frequencies between 10 Hz and 80 Hz and measure the wave images as described above.

– Using the measured values for the wavelength and the set frequency values, calculate the wave velocity ($v = \lambda \cdot f$) for each value pair.

e) Measuring the propagation velocity v_{gr} of a wave packet:

– To measure the propagation velocity v_{gr}, place a cover slide on the glass plate 20 cm from the wave exciter as a marker.

– If necessary, rotate the stroboscope disk out of the beam path and turn the amplitude knob **(d)** all the way to the left. Make sure that the wave exciter just touches the surface of the water over its entire length, and the generated wave fronts are still clearly visible at the marker.

– Actuate the stopclock and the pushbutton **(c)** for generating single wave simultaneously.

– Measure the time *t* which the wave packet requires to travel the marked distance *s*, and calculate the propagation velocity.

Measuring example and evaluation

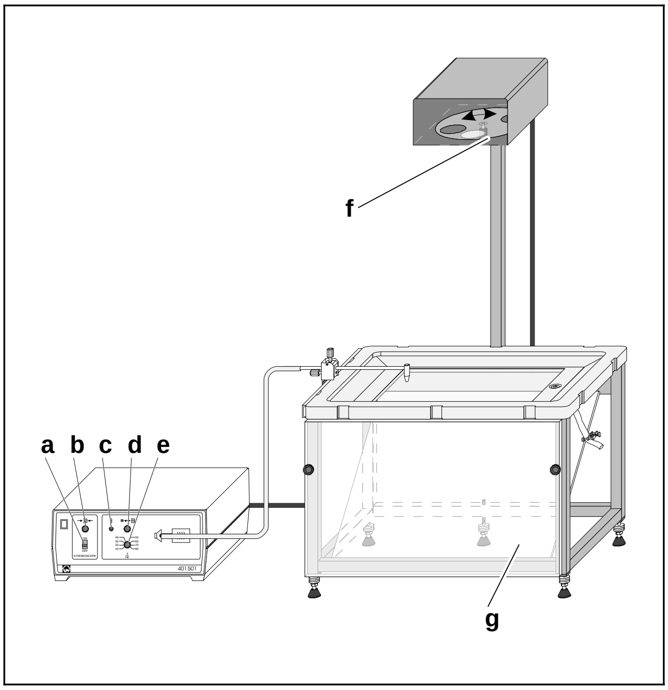
Fig. 1 shows two photographs with measurement examples.

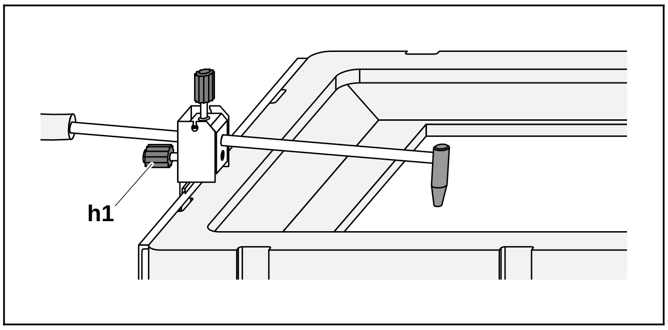
Table 1: Wavelength λ and wave velocity *v* of water waves as a function of excitation frequency *f*

$\frac{f}{\text{Hz}}$	$\frac{\lambda}{\text{cm}}$	$\frac{v}{\text{cm} \cdot \text{s}^{-1}}$
10	2.1	21
20	1.1	22
30	0.8	24
40	0.6	24
50	0.4	20
60	0.4	24
70	0.3	21
80	0.3	24

Table 2: Propagation velocity of a wave packet

$\frac{s}{\text{cm}}$	$\frac{t}{\text{s}}$	$\frac{v_{gr}}{\text{cm} \cdot \text{s}^{-1}}$
20	1	20





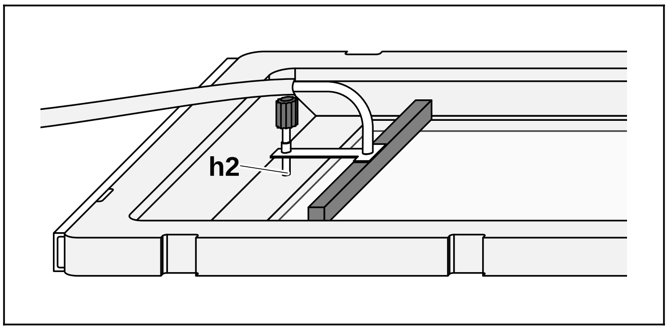


Fig. 2 Experiment setup (for exciting circular waves
- **a** Stroboscope switch
- **b** Knob (for fine adjustment of stroboscope frequency)
- **c** Pushbutton (single-wave excitation)
- **d** Knob (for adjusting amplitude of wave excitation)
- **e** Knob (for adjusting frequency of wave excitation)
- **f** Knurled screw (for manually turning stroboscope disk)
- **g** Observation screen

Fig. 3 Connecting a point-type exciter for circular waves
h1 Adjusting screw (for setting immersion depth)

Fig. 4 Connecting the exciter for straight waves
h2 Adjusting screw (for setting immersion depth)

Results

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 λ:

$$v = \sqrt{g \cdot \frac{\lambda}{2\pi} + \frac{\sigma}{\rho} \cdot \frac{2\pi}{\lambda}} \qquad \text{(I).}$$

(g: gravitational acceleration, σ: surface tension, ρ: density)

Above λ = 1.7 cm, the proportion due to weight predominates, and we speak of “gravity waves”. Here, the wave velocity increases with the wavelength. Below λ = 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 λ = 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

$$v = \sqrt{\frac{g \cdot \lambda}{2\pi} \cdot \tanh\left(\frac{2\pi h}{\lambda}\right)} \qquad \text{(II).}$$