The product of the frequency f and the wavelength λ of a wave train is approximately constant within a certain range. The phase velocity λ can be determined by measuring the wavelength f and with the frequency $c = \lambda \cdot f$ set at the ripple tank.

Materials
from the accessory set of 11260-99

1 Wave generator, single
1 Dipper

In addition, the following is also required

1 Ruler, transparent

Method

An image at rest of the wave pattern is generated by switching on the strobe lighting mode. The wave crests (bright) can be drawn on a sheet of paper on the bench, with which the wavelength of the water waves can be determined in the following.

Setup

The experiment can be carried out both with planar and with circular waves. It is advisable to use the single dipper due to its easier adjustability. This is then fixed to the exciter arm and moved to the bottom edge of the wave tank (Fig. 1).

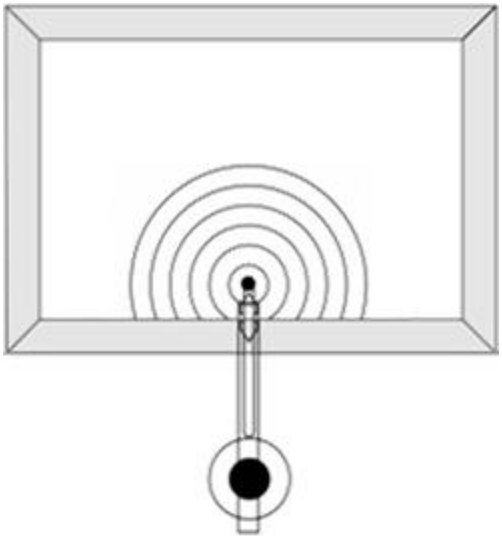

Figure 1: Experiment arrangement for generating circular waves.

Procedure

First the wave pattern is observed at different frequencies set at the ripple tank under stroboscopic lighting. It must be ensured that the frequency difference Δf between the stroboscopic lighting and the set excitation (wave generator) frequency is 0 Hz (standing wave pattern).

An excitation frequency of 10 Hz is then set. It is advisable to draw the wave crests and troughs on the sheet of paper on the drawing table first, so that the greatest possible distance between two wave crests (light stripes) can then be measured in normal room light and without the stroboscopic light. (Direct measurement of the wavelengths with stroboscopic lighting is difficult at lower frequencies.)

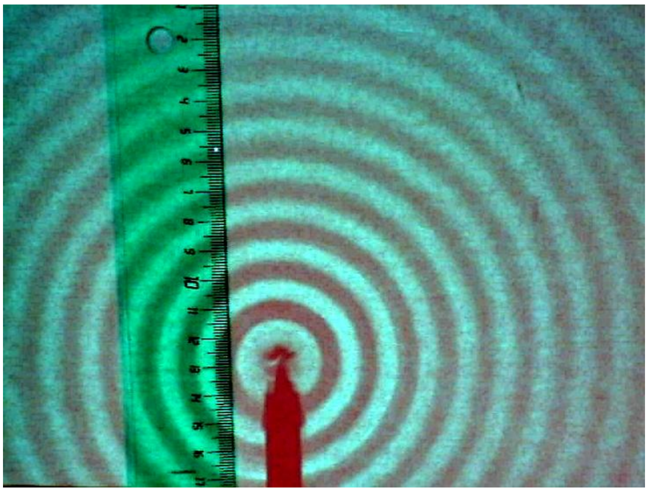

Figure 2: A ruler, placed on the drawing table, can be used to reliably determine the distance between two wave crests as far apart as possible.

This value is then divided by the number n of wave trains lying between the two wave crests and gives the wavelength λ (this method ensures greater measuring accuracy). The measured values together with the set frequency and the product of the wavelength and frequency $\lambda \cdot f$ are then entered in a table (see Table 1).

Note:
If measurements are taken on the bench, it must be noted that the actual wavelength can differ from the wavelength measured on the bench. This is because the optical conditions make the image on the bench appear larger. However, as relative changes in wavelength are involved here the resulting measurement error is the same for all measurements so that it can be ignored at the end. Overall, the actual propagation speed is slightly smaller, however this difference can be ignored.

The experiment is repeated for a frequency of 30 Hz as well as for two others, freely selectable frequencies between 10 Hz and 30 Hz. The table produced is supplemented with the additional measurement results obtained.

Note:
At frequencies lower than 10 Hz it is difficult to detect precise separation of the wave crests and troughs. This is due to the stroboscopic lighting, as the wave pattern can only be discerned for a very short time and the distance between two recognisable wave patterns is of course relatively large.

Results

The higher the excitation frequency f the smaller the corresponding wavelength λ. The following table shows a measurement example:

Table 1

f / Hz	$n\lambda$ / cm	n	λ / cm	$\lambda \cdot f$ / cm·s^{-1}
10	6.7	2.5	2.68	26.9
15	6.5	3.5	1.86	27.9
20	7.2	5.0	1.44	28.8
30	7.2	7.5	0.96	28.8

Interpretation

The phase velocity to be calculated from the relationship $c = \lambda \cdot f$ is approximately constant within the observed frequency interval and on average is around 28 cm/s.

A slight increase in phase velocity can be observed as the excitation frequency increases. This change is somewhat larger than the spread of the measured values due to measurement uncertainties. It can be explained, among other things, by the abnormal dispersion typical for water waves within this wavelength range (see note).

Note

The theory of wave propagation along a liquid surface provides the following formula for the phase velocity c:

$$c^2 = \frac{g\lambda}{2\pi} + \frac{2\pi\sigma}{\lambda\rho}. \quad (1)$$

If the surface tension for water $\sigma = 72.5 \cdot 10^{-3}\ \mathrm{Nm}^{-1}$ (20 °C) is inserted in this relationship for water; if the acceleration of gravity is $g = 9.81\ \mathrm{m\,s}^{-2}$ and a density of $\rho = 10^3\ \mathrm{kg\,m}^{-3}$ for water, at a wavelength of $\lambda = 1.44\ \mathrm{cm}$ the phase velocity is

$$c = \sqrt{0.0225 + 0.0316}\ \frac{\mathrm{m}}{\mathrm{s}} = 0.233\ \frac{\mathrm{m}}{\mathrm{s}}. \quad (2)$$

The experimentally determined value of 28.8 cm/s = 0.288 m/s is therefore above the theoretical value, which can be explained by projection errors from the plane of the wave pattern to the plane of the paper.

Further phase velocity dependencies result from the aforementioned formula as follows:

1. The surface tension is substantially reduced by adding soap solution. For $\sigma = 0$, formula (1) gives a phase velocity ($\lambda = 1.44\ \mathrm{cm}$) of 15 cm/s.

2. Formula (1) applies to deep water only. If the water depth is less than λ, the propagation velocity is reduced (in the boundary case of insignificantly small water depth, irrespective of λ, the following applies: $c = \sqrt{gh}$. This deceleration becomes increasingly noticeable with increasing wavelength.

