LD Physics Leaflets

P1.6.3.2

Determining the phase velocity of circularly polarized thread waves in the experiment setup after *Melde*

Objects of the experiment

- Generating standing, circularly polarized thread waves for various tension forces *F*, thread lengths *s* and thread densities *m**.
- Determining the phase velocity *c* of thread waves as a function of the tension force *F*, the thread length *s* and thread density *m**.

Principles

The propagation speed of a wave in a medium is calculated using *d'Alembert's* wave equation. For an elastically tensioned thread, we compare e. g. the restoring force acting on a section of the thread deflected from its resting position with the inertial force of this piece of thread. The result for the propagation speed is

$$c = \sqrt{\frac{F}{A \cdot \rho}}$$

(F = tension force, A = thread cross-section, ρ = density of the thread material)

respectively

$$c = \sqrt{\frac{F}{m*}} \quad \text{with } m* = \frac{m}{s} \qquad \text{(I)}$$

(m = mass of thread, s = thread length).

In the experiment arrangement after *Melde,* standing, circularly polarized waves are generated in a thread with known length *s*. The tension force *F* is varied until waves with the wavelength

$$\lambda_n = \frac{2s}{n} \qquad \text{(II)}$$

n = number of oscillation nodes)

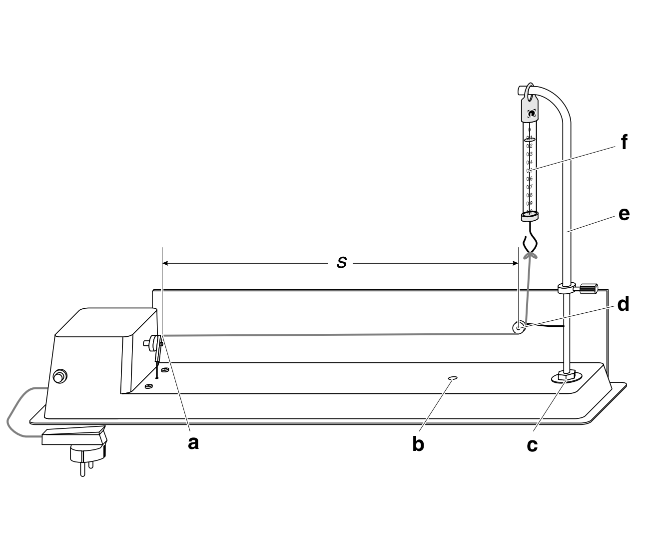
are obtained. The additional determination of the frequency *f* using a stroboscope enables calculation of the propagation speed according to the formula

$$c = \lambda \cdot f \qquad \text{(III)}$$

If the mass and the length of the thread are additionally measured, it becomes possible to verify equation (I).

The stroboscope is recommended not only for measuring the frequency: when the standing thread wave is illuminated with light flashes at a frequency approximating the excitation frequency, the oscillations of the thread seem to slow down and the circular polarization of the waves becomes visible in a highly impressive manner.

Fig. 1 Arrangement for the experiment after *Melde*
(a) Cam
(b) Mounting point for thread length s = 0.35 m
(c) Mounting point for thread length s = 0.48 m
(d) Deflection pulley
(e) Holding arm
(f) Dynamometer



Setting up and carrying out the experiment

Set up the experiment as shown in Fig. 1.

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Apparatus

1 Vibrating thread apparatus	401 03
1 Stroboscope, 220 V, 50 Hz	451 28
1 School and lab balance	315 05
1 Tape measure, 2 m	311 77

Preparation:

– Cut up the thread supplied with the apparatus into three pieces of different lengths:
– Cut off a piece 0.65 m long as thread 1 for experiment part a.
– Cut off a piece 0.50 m long as thread 2 for experiment part b.
– Cut off a piece approx. 2.60 m long as thread 3, fold it over itself four times; entwine the thread pieces together and tie their ends.

Important: start each measurement with the completely detensioned thread and vary the tension by slowly and carefully moving holding arm **(e)**.

a) Wavelength λ and phase velocity c as a function of the tension force F

– Set up the holding arm **(e)** of the vibrating thread apparatus at position **(c)**.
– Tie one end of thread 1 to cam **(a)**.
– Tie a loop in the other end and hang this on the dynamometer **(f)**.
– Measure the distance between cam **(a)** and the center of the deflection pulley **(d)** (= thread length s) and write this value in the experiment log.
– Switch on the motor of the apparatus.
– With the adjusting screw loosened, vary the force F by changing the height of the holding arm **(e)** until a standing wave of maximum amplitude with the wavelength $\lambda = 2$ s is formed (one oscillation antinode).
– Read off the corresponding force F_1 and write this value in the experiment log.
– By slowly and carefully varying the height of holding arm **(e)**, determine the forces F_n at which standing waves with n = 2, 3, 4 and 5 antinodes are formed.
– For each standing wave, use the stroboscope to determine the excitation frequency f. To do this, start from the maximum stroboscope frequency and slowly reduce the frequency until a simple standing sinusoidal wave first becomes visible.
– Write down the number n of nodes, the corresponding force F_n and the frequency f in the experiment log.
– Switch off the motor.
– Untie the thread and measure the mass m_0 and the length s_0 of the thread so that the density $m* = \frac{m_0}{s_0}$ of the thread can be calculated.

b) The influence of thread length *s* and thread mass *m*:

– Set up holding arm **(e)** of the vibrating thread apparatus at position **(b)**.
– Attach thread 2.
– Measure the distance between cam **(a)** and the center of the deflection pulley **(d)** (= thread length s) and write this value in the experiment log.
– Switch on the motor of the apparatus.
– Determine the forces F_n and the frequencies f at which standing waves with n = 1, 2, 3 and 4 anti nodes are formed.
– Switch off the motor.
– Measure the mass m_0 and the length s_0 of the thread.

c) Wavelength λ and phase velocity *c* as a function of the density *m:**

– Set up the holding arm **(e)** of the vibrating thread apparatus at position **(c)**.
– Attach thread 3.
– Switch on the motor.
– Determine the forces F_n and the frequencies f at which standing waves with n = 1, 2, 3, 4, 5 and 6 antinodes are formed.
– Switch off the motor.
– Measure the mass m_0 and the length s_0 of the thread.

Measuring example

Tables 1 a, b, and c show the measurement results for experiment parts a), b) and c).

Table 1: Frequency f and tension force F_n for a standing wave with n oscillation nodes

a) Thread 1 with s = 0.48 m, $m^* = 0.43\ \frac{\text{g}}{\text{m}}$

n	$\frac{f}{\text{Hz}}$	$\frac{F}{\text{N}}$
1	47	0.875
2	48	0.225
3	48	0.1
4	48	0.05
5	48	0.025

b) Thread 2 with s = 0.35 m, $m^* = 0.43\ \frac{\text{g}}{\text{m}}$

n	$\frac{f}{\text{Hz}}$	$\frac{F}{\text{N}}$
1	47	0.5
2	47	0.125
3	48	0.05
4	48	0.025

c) Thread 3 with s = 0.48 m, $m^* = 1.74\ \frac{\text{g}}{\text{m}}$

n	$\frac{f}{\text{Hz}}$	$\frac{F}{\text{N}}$
2	46	0.92
3	47	0.425
4	47	0.25
5	47	0.15
6	47	0.1

Evaluation and results

Table 2: Evaluation of the measurement results from Table 1

a) Thread 1 with s = 0.48 m, m^* = 0.43 $\frac{g}{m}$

n	$\frac{\lambda}{m}$	$\frac{c}{m\,s^{-1}}$	$\frac{\sqrt{\frac{F}{m^*}}}{m\,s^{-1}}$
1	0.96	45.1	45.1
2	0.48	23.0	22.8
3	0.32	15.4	15.2
4	0.24	11.5	10.8
5	0.19	9.1	7.6

b)Thread 2 with s = 0.35 m, m^* = 0.43 $\frac{g}{m}$

n	$\frac{\lambda}{m}$	$\frac{c}{m\,s^{-1}}$	$\frac{\sqrt{\frac{F}{m^*}}}{m\,s^{-1}}$
1	0.70	32.9	34.1
2	0.35	16.5	17.0
3	0.23	11.0	10.8
4	0.18	8.6	7.6

c) Thread 3 with s = 0.48 m, m^* = 1.74 $\frac{g}{m}$

n	$\frac{\lambda}{m}$	$\frac{c}{m\,s^{-1}}$	$\frac{\sqrt{\frac{F}{m^*}}}{m\,s^{-1}}$
2	0.48	22.1	23.1
3	0.32	15.0	15.6
4	0.24	11.3	12.0
5	0.19	8.9	9.3
6	0.16	7.5	7.6

The wavelengths λ_n calculated from the number of oscillation nodes n according to equation (II) are given in Tables 2 a, b and c. The tables also contain the phase velocities calculated using equation (III) as well as the expression $\sqrt{\frac{F}{m^*}}$. Fig. 2 shows the graph of $\sqrt{\frac{F}{m^*}}$. As the measured values lie with good approximation on a straight line through the origin with the slope 1, this confirms equation (I).

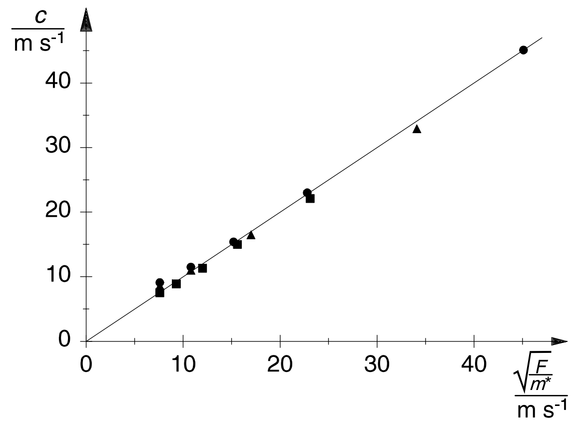

Fig. 2 Graph of $c = f(\sqrt{\frac{F}{m^*}})$.

Circles: data from Table 2 a

Triangles: data from Table 2 b

Squares: data from Table 2 c