

Related topics

Interference, reflection, diffraction, acoustic waves, stationary waves, Huygens-Fresnel principle, use of an interface.

Principle and task

- Two acoustic sources emit waves of the same frequency and if their distance is a multiple of the wavelength, an interference structure becomes apparent in the space where the waves are superimposed.
- An acoustic wave impinges perpendicularly onto a reflector, the incident and the reflected wave are superimposed to a stationary wave. In case of reflection, a pressure antinode will always occur at the point of reflection.
- An acoustic wave impinges on a sufficiently narrow slot, it is diffracted into the geometrical shadow spaces. The diffraction and the interference pattern occurring behind the slot can be explained by means of the Huygens-Fresnel principle and confirm the wave characteristics of sound.

Equipment

Sound head	03524.00	2
Measuring microphone	03542.00	1
Flat cell battery, 9 V	07496.10	1
Screen, metal, 300×300 mm	08062.00	1
Function generator	13652.93	1
Right angle clamp -PASS-	02040.55	1

Stand tube	02060.00	4
Barrel base -PASS-	02006.55	4
Bench clamp -PASS-	02010.00	1
Plate holder	02062.00	1
Meter scale, demo. l = 1000 mm	03001.00	1
Silk thread, 200 m	02412.00	1
Weight holder 1 g	02407.00	1
Slotted weight, 10 g, black	02205.01	2
Connecting cord, 1000 mm, red	07363.01	1
Connecting cord, 1000 mm, blue	07363.04	1
Movement sensor with cable	12004.10	1
Adapter, BNC-socket/4mm plug pair	07542.27	2
Adapter, BNC socket - 4 mm plug	07542.20	1
COBRA-interface 2	12100.93	1
PC COBRA data cable RS232, 2 m	12100.01	1
Softw. COBRA Rotation (Win)	14295.61	1
Basic Softw. f. PHYWE Windows prog.	14099.61	1

The PHYWE WINDOWS® Basic Software (14099.61) must have been installed once on the used computer for the software to work.

Problems

1. To measure the interference of acoustic waves.
2. To analyze the reflection of acoustic waves – stationary waves.
3. To measure the diffraction at a slot of acoustic waves.

Fig. 1: Experimental set-up for interference measurements.

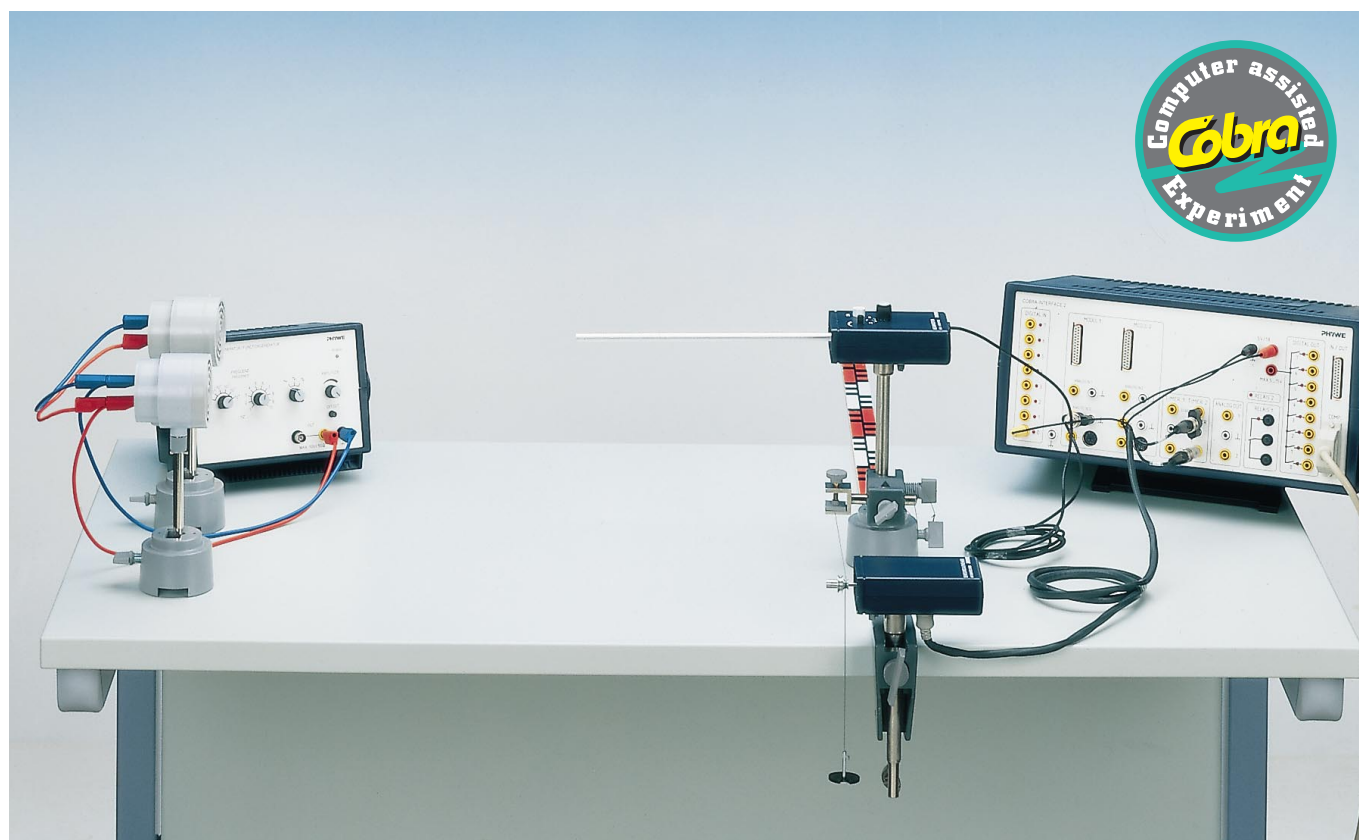
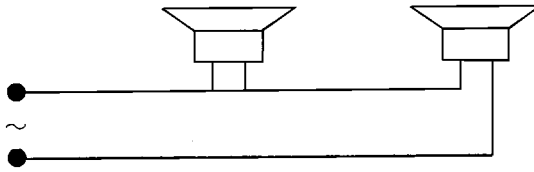


Fig. 2: Wiring diagram.

**Set up**

- Interference: according to Fig. 1: the loudspeakers are connected as a function of the output resistance of the signal generator according to Fig. 1 or according to the wiring diagram in Fig. 2.
- Stationary waves: experimental set up according to Fig. 3.
- Diffraction: according to Fig. 4.

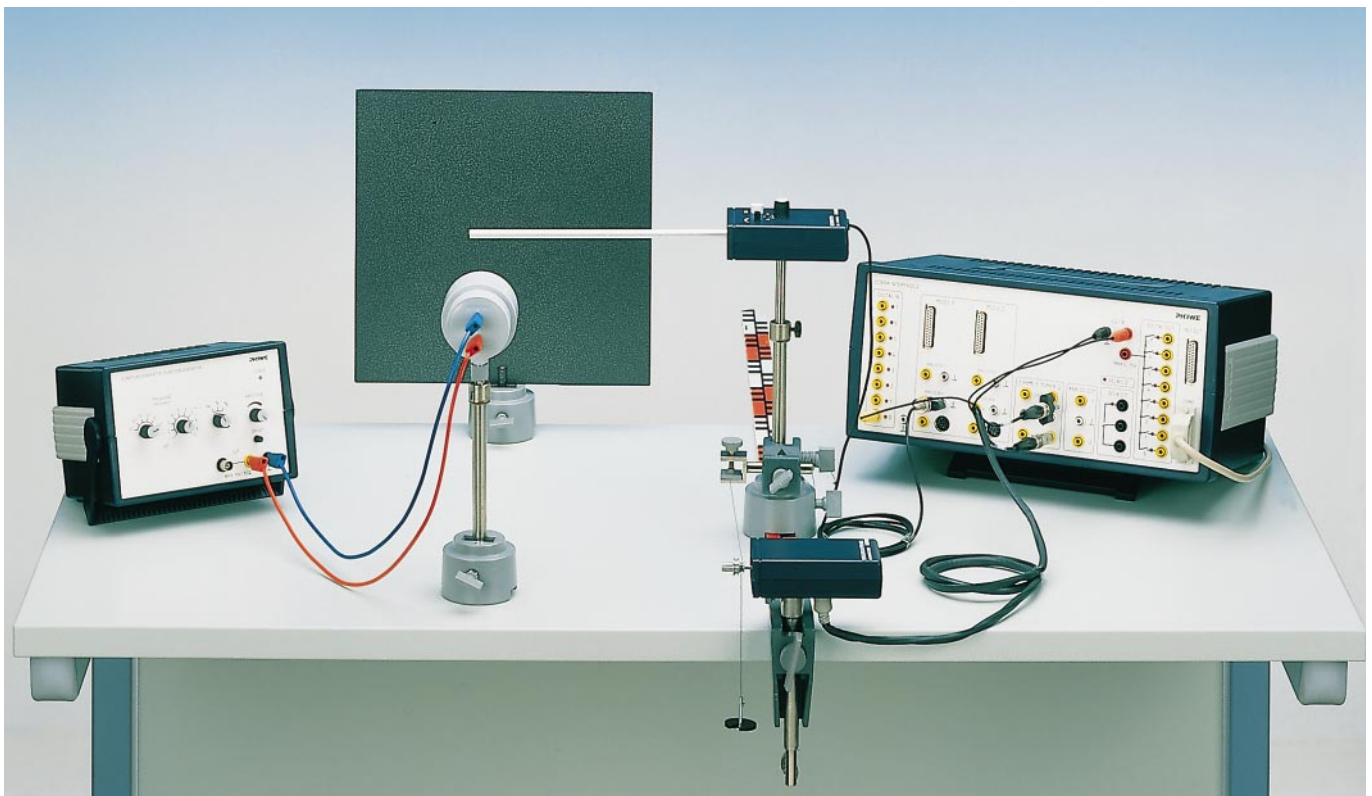
The silk thread is wound once over the smaller of the two thread grooves of the movement recorder. The cable of the movement recorder is connected to the COBRA interface according to Fig. 5.

Procedure

- According to whether the COBRA interface is connected to the computer port COM1 or to COM2, "CH3(x)_COM1" or "CH3(x)_COM2" is started by clicking twice on the icon.

- Press the <Start> button. The sampling rate can be modified by shifting the <Delta t/ms> slide. For every computer, there is a maximum sampling rate. If the sampling time is too short, data communication errors may occur. It must be made sure that when <Digit> is pressed, the number of displayed measurement values corresponds to the adjusted sampling rate. For <Delta t/ms> = 300 ms, the analogue voltage display "y" should thus change about three times every second. If display changes are less frequent, sampling time <Delta t/ms> must be increased.
- Set amplification on the measuring microphone to a medium position. The selection switch on the microphone is set to the central position (signal operation). Press measurement range adjustment (CH3 / V) <10>.
- If strong fluctuations of the measured voltages occur during measurement, it is recommended to lift the measuring microphone and to displace it manually. Gritting noises of the barrel base on the table may cause distortions of the measurement signal. Set the <Average> adjustment to 1.
- Calibration of the movement recorder:
to measure the path with the movement recorder, only the smaller of the two thread grooves is used. As the relation between the linear path and the number of revolutions of the thread groove depends on the used thread and on the sampling time <Delta t/ms>, the path measuring system must be calibrated once.
One edge of the barrel base is situated exactly on a dm subdivision of the scale (e.g. 800 mm). Now a path length, (e.g. 0.1 m), is entered into the corresponding input window "x0" and the "Enter" key is pressed on the keyboard.

Fig. 3: Experimental set-up for the measurement of stationary waves.

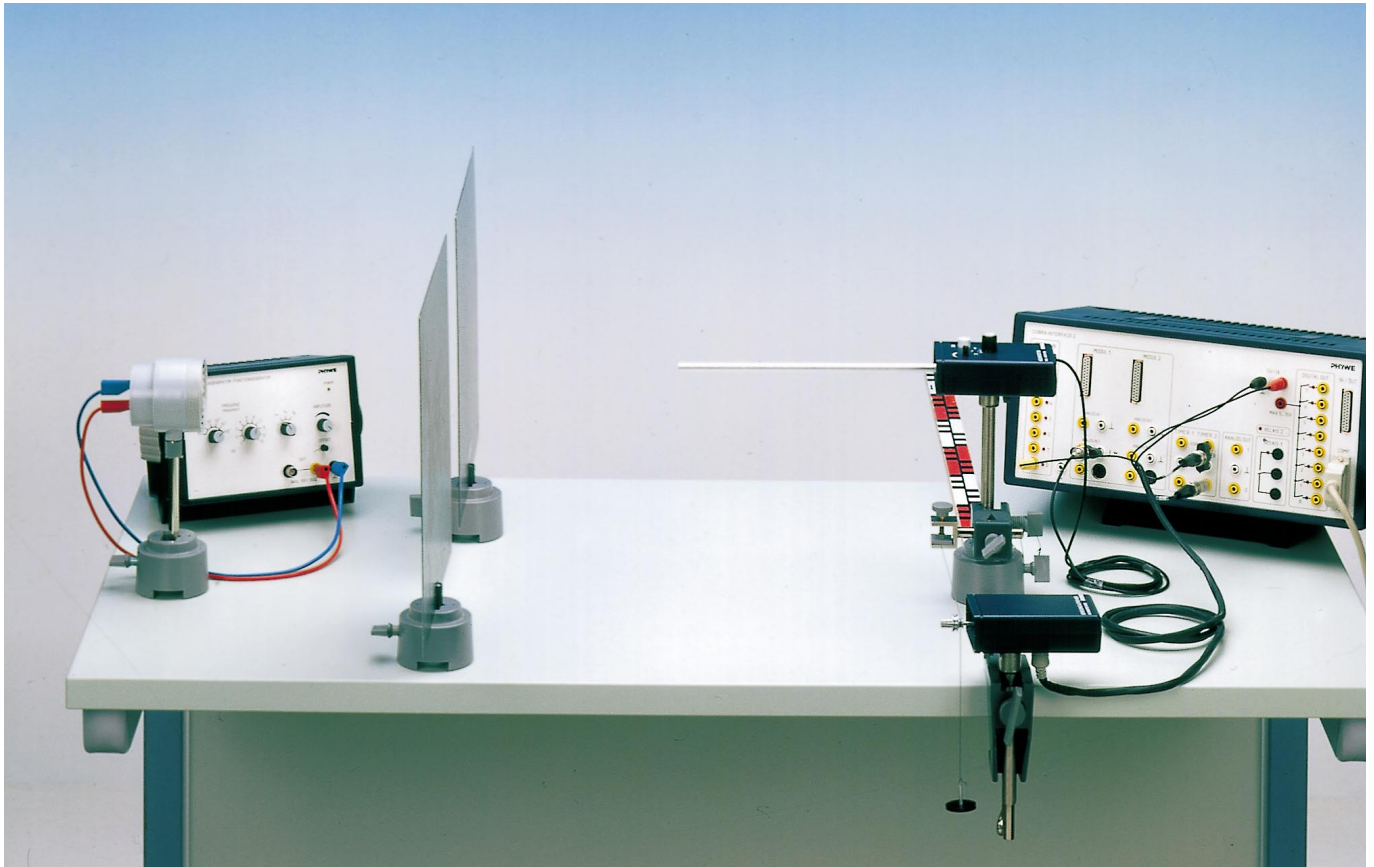


If the <Stop> button is displayed, it is clicked at to start with and then the appearing <Start> button is pressed. If the <Start> button was visible from the beginning, it is pressed only once. In any case, measurement value recording must be switched off once and then on again. This switching off and on causes the value of the path sensor to be reset to 0.000 m. The value 0.0 must be displayed in the input field "d0". Press the <Digit> and the <X Sensor> buttons. The barrel base is now slowly and regularly shifted towards the movement recorder by the distance "x0" set on the scale. The length "x0" relates to the scale and not to the value displayed on the monitor. After this, the <Cal> button situated below the "x0" input window is pressed. Calibration is now concluded. For every new start of the measurement programme, this calibration is automatically taken into account and need thus not be repeated. New calibration only is required if the tread is changed or another sampling time <Delta t/ms> is set. If a negative path is measured, although this is not expected, the corresponding numerical value "-" must be entered with a - sign and calibrated again.

- 1. Measurement with path sensor and permanent automatic measurement value recording:
 - Set the barrel base to the initial position (interference: microphone points to the centre between the two loudspeakers – stationary waves: microphone before the loudspeaker – diffraction: shift the microphone before the slot) and press <X Sensor> and <P>.

- Switch <Start> <Stop> off and on once, the red <Stop> button must be visible after this. If <Digit> is pressed, voltage y is displayed in volts and the path x as 0.000 m. During the recording of measurement values, one may switch continuously back and forth between <Digit> and <Plot>. For the <Plot> function, a yellow measurement point appears at the position x at the beginning of the measurement. This moves up and down due to fluctuations of luminous intensity.
- Press <Reset> to set the number of measurement points back to zero and to delete the graph.
- For the interference and acoustic interference measurement, the microphone is shifted to an edge with the <Start> button switched on (about 1 cm/s) to start with, and the <Reset> button is pressed again.
- To carry out the measurement, the barrel base is slowly (about 0.5 cm/s) and regularly moved. A measurement plot is being recorded continuously. Measurement points are only entered into the graph if the tread groove of the movement recorder is moved. If the barrel base is stopped, no new measurement points appear in the graph. Recording of measurement values stops after about 50–80 cm. For this, the <P> button is pressed, followed by the <X Sensor> button and finally by the <Stop> button.

Fig. 4: Experimental set-up for the measurement of diffraction.



- 2. Measurement with path sensor and manual measurement value confirmation:
this measurement method is recommended if background noise influences measurement results.
- Set the barrel base to the initial position (interference: microphone points to the centre between the two loudspeakers – stationary waves: microphone before the loudspeaker – diffraction: shift the microphone before the slot) and press <X Sensor>.
- Switch <Start> <Stop> off and on once, the red <Stop> button must be visible after this. During the recording of measurement values, one may switch continuously back and forth between <Digit> and <Plot>. For the <Plot> function, a yellow measurement point appears at the position x at the beginning of the measurement. This moves up and down due to noise.
- Press <Reset> to set the number of measurement points back to zero and to delete the graph.
- For the interference and acoustic interference measurement, the microphone is shifted to an edge with the <Start> button switched on (about 1 cm/s) to start with, and the <Reset> button is pressed again.
- Set <Average> to about 30.
- Click on the <Enter> button on the screen in order to take over the actual pair of values (x , y) into the computer memory and to plot it.
- The barrel base is slowly and regularly moved on about 1 cm. Once the new voltage value has stabilised after a few seconds, the <Enter> button is clicked on again. Proceed in the same way for all further measurement points.

Result

- Interference:
Two acoustic emitter heads are used as acoustic sources connected in parallel or in series to a signal generator. Local distribution of the oscillating acoustic pressure is examined by means of a microphone which is shifted parallel to the line joining the acoustic emitter heads. Due to the changing distances r_a and r_2 between the microphone and the acoustic emitter heads, and the thus modified different travelled distances of the waves, the latter superimpose with different path differences at the point of measurement. If the acoustic emitter heads are operated at the same phase, the path difference results directly from the difference between the travelled distances. If this difference is an even integer multiple of the wavelength λ ,

$$\Delta r = n \cdot \lambda, n = 0, 1, 2, \dots,$$

the oscillating pressure amplitudes are added. In places where the above condition is fulfilled, pressure oscillation is maximum. If on the other hand the difference of the travelled distances is an odd integer multiple of the half wavelength,

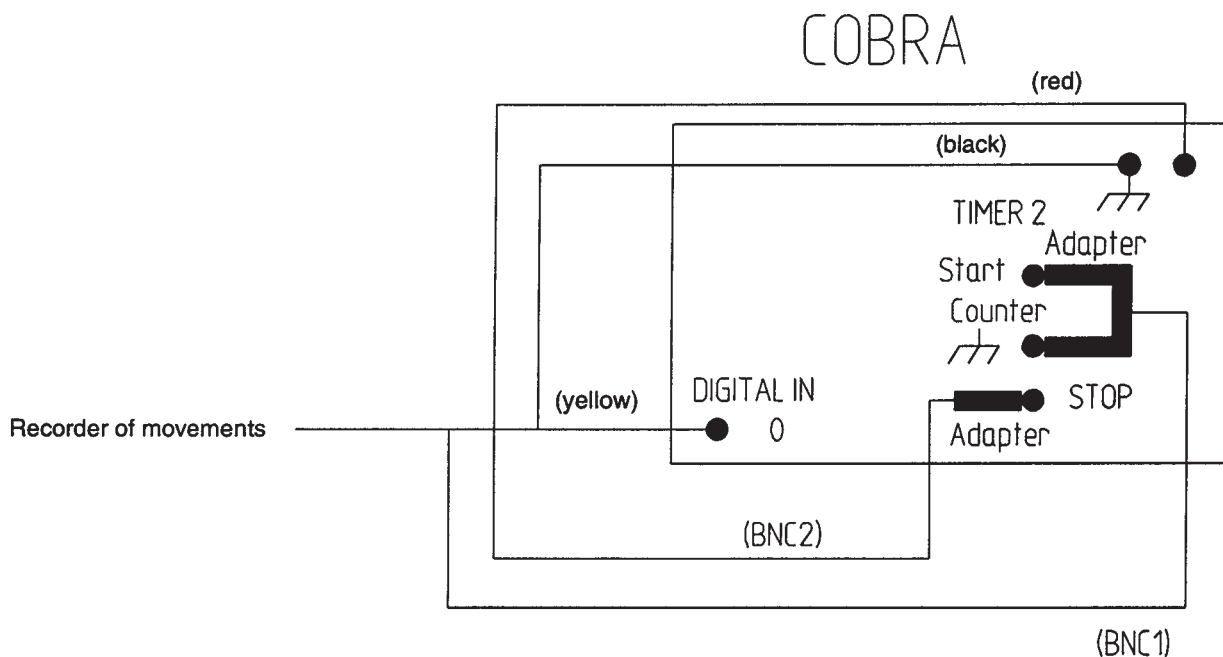
$$\Delta r = \frac{(2n - 1) \lambda}{2}, n = 1, 2, 3, \dots,$$

the instant values of the oscillating acoustic pressure have different signs. In this case, the total amplitude is the difference of the single amplitudes and displays a minimum. The following is valid for the acoustic wavelength λ :

$$\lambda = c / f,$$

where c is the speed of sound and f the frequency.

Fig. 5: Connecting of the movement recorder to the COBRA interface.



According to Fig. 6, the following approximate relation is obtained for the path difference of the single waves:

$$r_1 + r_2 = 2s \text{ for } l > d$$

$$\Delta r = \frac{a \cdot d}{s}$$

and with $\sin \alpha = \frac{a}{s}$

$$\Delta r = d \sin \alpha.$$

One thus obtains for the angles under which peaks and minima of the oscillating acoustic pressure occur:

$$\sin \alpha_{\max} = \frac{n \cdot \lambda}{d}, n = 0, 1, 2, \dots$$

$$\sin \alpha_{\min} = \frac{(2n-1)\lambda}{2d}, n = 1, 2, 3, \dots$$

The points of observation a are calculated according to

$$a = l \cdot \tan \alpha.$$

From the geometry for the present example of measurement:

$$l = 0.25 \text{ m}$$

$$d = 0.2 \text{ m}$$

$$c = 340 \text{ m/s}$$

$$f = 3170 \text{ Hz}$$

one obtains:

$$\alpha_{\max} = 32.43^\circ \text{ - distance of the peaks from the central peak}$$

$$a_{\max} = 0.159 \text{ m and } \alpha_{\min} = 15.55^\circ \text{ - distance of the minima from the central minimum } a_{\min} = 0.070 \text{ m.}$$

These calculated results agree quite well with the measurement results displayed in Fig. 7.

Indication: noise may be reduced if the measurement is carried out with manual confirmation of the measurement values and higher average values ($\langle \text{Average} \rangle = 30$).

— Stationary waves:

The acoustic waves emitted by an acoustic emitter head are reflected in a reverberating manner on a metallic screen, that is, the oscillating acoustic pressure is reflected without phase shift. An intensity peak is measured at the metallic plate (Fig. 8, right side). Incident and reflected waves follow the relation

$$I = A \sin \left[2\pi \left(\frac{ct-x}{\lambda} \right) \right] + A \sin \left[2\pi \left(\frac{ct+x}{\lambda} \right) \right]$$

concerning the ideal assumption that the amplitudes of both waves are identical. If the sum is converted to a product according to the addition theorems of trigonometric functions, one obtains:

$$I = 2A \cos \frac{2\pi x}{\lambda} \sin \frac{2\pi ct}{\lambda}.$$

This relation shows that all oscillating particles go through zero at the moment

$$t = \frac{n}{2} \cdot \frac{\lambda}{c} = \frac{n}{2} \cdot T, n = 1, 2, 3, \dots$$

Amplitude which only depends on location

$$2A \cos \frac{2\pi x}{\lambda}$$

displays peaks when

$$x = \frac{n}{2} \lambda, n = 1, 2, 3, \dots$$

is fulfilled. For a frequency $f = 3170 \text{ Hz}$, the wavelength $\lambda = 0.107 \text{ m}$. If in figure 8 the average distance between the peak is measured, one obtains for the present measurement example, in good agreement with theory, a wavelength $\lambda = 0.104 \text{ m}$.

Indication: noise may be reduced if the measurement is carried out with manual confirmation of the measurement values and higher average values ($\langle \text{Average} \rangle = 30$).

— Diffraction:

When a plane wave front meets a slot whose width is a multiple of the wavelength, according to the Huygens-Fresnel principle, the surface limited by the slot may be considered as location of many exciting points. The ele-

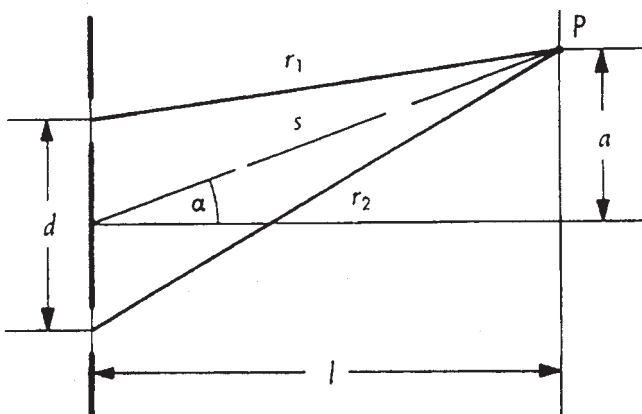


Fig. 6: Travelled lengths for interference.

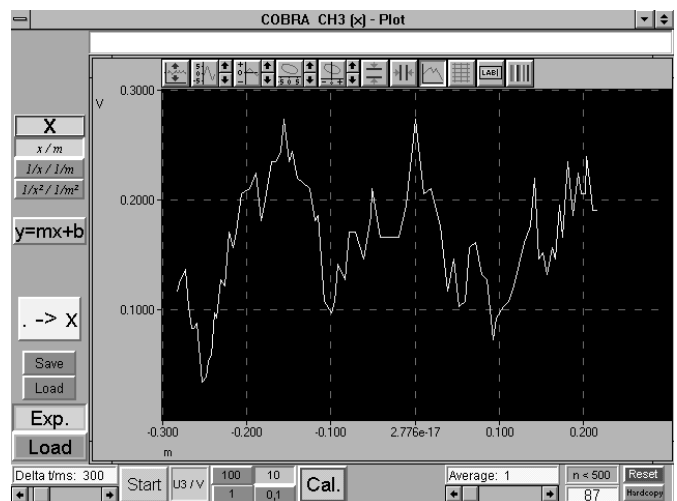


Fig. 7: Interference structure, the smaller visible peaks are caused by noise and reflections of acoustic waves on the table top and due to the proximity of other units.

mentray waves coming from them interfere and fill the space behind the slot with a distribution of peaks and minima of the oscillating acoustic pressure. The spatial position of the interference structure can be calculated if one imagines the slot subdivided into a number of stripes of the same width. According to the number n of stripes, the elementary waves coming from the exciting points interfere under definite angles α_n in such a way that corresponding waves amplify or extinguish one another. Extinction is given for a slot width d and an acoustic wavelength λ when the following relation is valid:

$$\sin \alpha = \frac{n \cdot \lambda}{d}, n = 1, 2, 3, \dots,$$

Amplification occurs in the direction of propagation of the acoustic wave, that is, for $\alpha = 0$ as well as for the angle α with

$$\sin \alpha = \frac{(2n + 1) \lambda}{2d}, n = 1, 2, 3, \dots$$

that is, the interference peaks and minima are situated on straight lines going through the middle of the slot. The angle by the lines depends on the relation between the wavelength and the width of the slot. The angle under which peaks and minima occur can be calculated according to Fig. 9 from

$$\tan \alpha = \frac{a}{l}$$

and can be compared to the previously named relations. The following disposition was selected for this measurement example:

distance between loudspeaker and slot	34 cm
distance between slot and microphone tip (l)	25 cm
slot width (d)	4.5 cm
frequency	22 kHz

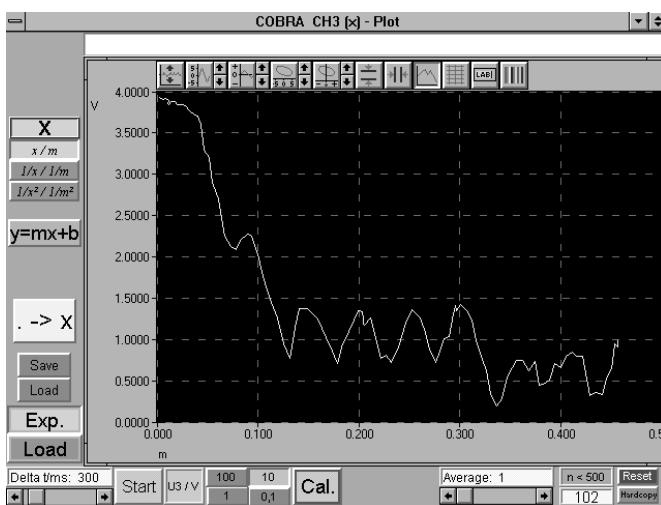


Fig. 8: Stationary waves: as the acoustic intensity decreases from left to right and the microphone is moved away from the acoustic source, waves running in both directions do not quite cancel each other.

For a room temperature of 22°C and a speed of sound $c = 345$ m/s, one obtains a wavelength $\lambda = 1.57$ cm.

The microphone was shifted towards both sides up to a lateral distance $a = 20$ cm from the zero position. (If the available table surface is sufficient, it is recommended to choose a as large as possible!). Figure 10 shows the amplitude distribution of a measurement example. The zero order peak corresponds to position zero and the following minima and peaks are disposed quite symmetrically about this. (In Fig. 10, the zero order peak is offset by about 3 cm against the origin of the diagram. The reason for this is due partly to superimposition of the diffracted wave with waves due to reflections at obstacles and also to the lack of precision of the position of the microphone on the point of symmetry of the measurement set up at the beginning of measurements. As, however, only the relative positions of peaks and minima are relevant for the evaluation, this offset is of no importance).

For the distance of minima and peaks of order zero, $a = \pm 0.09$ m is read from Fig. 10. From the measurement geometry, one thus obtains $\alpha_{\text{measured}} = \pm 19.8^\circ$.

From theoretical considerations, one obtains for $n = 1$ the angle $\alpha_{\text{theoretic}} = \pm 20.4^\circ$. The position of the peaks of the first order thus is:

$$\alpha_{\text{measured}} = \pm 32.6^\circ \text{ (with } a = 0.16 \text{ m) and } \alpha_{\text{theoretic}} = \pm 31.6^\circ.$$

Indications

The results of all partial experiments depend strongly on the acoustic characteristics of the environment. The following points should be taken into account:

- In the case of experiments which last longer, it is recommended to work with acoustic frequencies above the hearing limit of about 16 kHz, if experimental conditions will allow it, in order to keep disturbances due to noise as low as possible.
- If the corresponding geometric conditions are modified, the acoustic field should be scanned in large steps to start with, in order to have an idea of the shape of the acoustic fields.

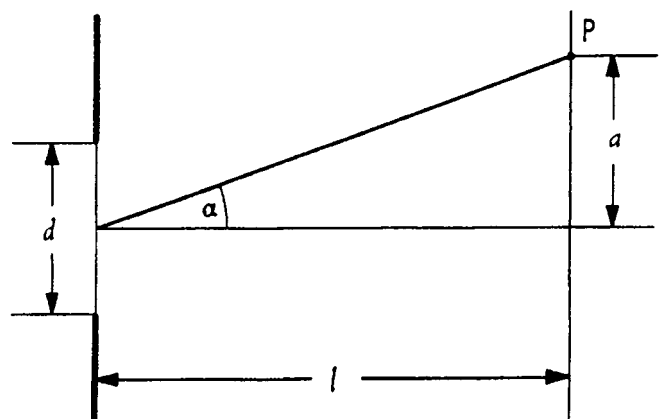


Fig. 9: Geometric set up to evaluate acoustic diffraction.

- Vibrations of the table top generate acoustic waves which may distort measurement results. Such types of disturbances can be avoided to a large extent, if power supply units and measuring instruments are set up as far as possible of the actual experimental set up. Especially, the fan of the computer should not be near the microphone.
- Not only exterior acoustic sources, but also reflected acoustic waves cause distortions of the actual measurement signal. All experiences should thus be carried out as far away as possible from walls, cabinets, etc. Reflections on the experimenting table top can be damped by covering the table top with sound absorbing material such as cloth or foam rubber between acoustic source and microphone. Such reflections can be avoided altogether if it is possible to set up the acoustic source and the microphone on the facing edges of two separate tables.
- Wavelength λ and frequency f of the acoustic wave depend on each other over the speed of sound c . The speed of sound itself is temperature dependent and can be calculated according to

$$c(t) = 333.1 \cdot \sqrt{1 + \frac{t}{273} \frac{m}{s}},$$

where t must be expressed in °C.

- <Save> (green) saves the recorded measurement data as ASCII file on the hard disk or on a floppy disk. These data can be read and processed by usual spread sheet or text processing programmes. The files should have *.AFD as a extension (**A**SCII **F**ile **D**ata), so the measurement data file can be easily identified.
- <Load> (green) loads a previously saved measurement file into the RAM memory of the computer for processing and representation.
In order to display the thus loaded measurement series graphically, the blue <Load> button situated below the <Exp.> button must be pressed. If, on the contrary, the <Exp.> button is pressed, the graph of the actual experiment will always be displayed. The <Exp.> and <Load> buttons thus switch between the loaded measurement and the actual measurement.

- Above the graph there is a white line into which a title may be entered after clicking on it.
- The <Hardcopy> button is used to print out the complete screen on a printer running under WINDOWS®. Before using this button, however, the colour combination of the diagram should be modified in order to save ink ribbon or cartridge. To achieve this, the button with rainbow colours situated on the right side above the graph (to the right next to the <LAB> button) is pressed. The following setting is recommended for print out:
Cart white
Data black.
- Starting from the left side, the other buttons above the graph are used for the following purposes:
 - Extending and compressing the y axis, the arrows do this in steps, the button with the curve allows to enter maximum and minimum values over the keyboard.
 - Shifting the measurement curve in the y direction without changing the scale (arrows).
 - Extending and compressing the x axis, the arrows do this in steps, the button with the curve allows to enter maximum and minimum values over the keyboard.
 - Shifting the measurement curve in x direction without changing the scale (arrows).
 - Introduction of horizontal cursor lines which can be moved with the left mouse buttons. The absolute and relative values of each position are displayed below the graph.
 - Introduction of vertical cursor lines which can be moved with the left mouse buttons. The absolute and relative values of each position are displayed below the graph.
 - Connection of the measurement points through polygonal lines.
 - Introduction of a grid, of an origin coordinate system or of a single coloured background.
 - Modification of the x and y axis indications.
 - Modification of the graph colours.
- When displayed and pressed, the <.->x> button introduces the measurement points magnified into the polygonal line of the graph. According to the number of measurement points, carrying out of the function may last a few seconds.
- The programme is terminated when the symbol situated in the uppermost left corner of the screen is clicked on twice.
- The used graphic set-up has a resolution of 640×480 pixels. If a monitor with higher resolution is used, the programme will only use a corresponding picture segment on the upper left corner of the monitor.

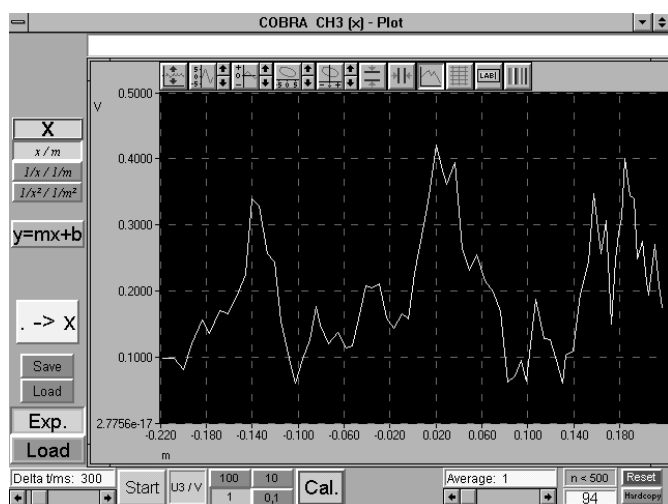


Fig. 10: Measurement example, diffraction through a slot.