# Stationary Sound Waves in a Kundt Tube

## 1 Incentive

In this experiment, the relationship between the wavelength, frequency and speed of a sound wave will be illustrated in an eidetic manner.

## 2 Theory

To begin with, some basic properties of acoustic will be presented.
A Kundt tube is a tube in which the diameter is smaller than 1/4 of a used wavelength. In this case, it can be assumed that a planar wave propagates in the pipe and not a spherical wave.

The following values can be used to describe a planar sound wave:

**1** **Sound velocity *c***: Specifies how fast the sound wave propagates, it is not dependant on the location of the source.

**2** **Sound pressure *p***: Indicates the pressure in the carrier medium which exists in addition to the normal air pressure at a particular location. *p* can assume negative values.

**3** **Sound particle velocity *v***: Specifies how quickly the individual vibrating particles of the carrier medium are moving. This depends on the location.

**4** **Frequency** $\nu$ i.e. **wavelength $\lambda$**: These each depend on the relationship $c = \lambda \cdot \nu$

Where the pressure is maximum or minimum, the gas particles do not move. In the middle between maximum and minimum pressure, the particles are subjected to the largest accelerating and move there with the greatest velocity *v*. Pressure and velocity are thus phase shifted by 90°.

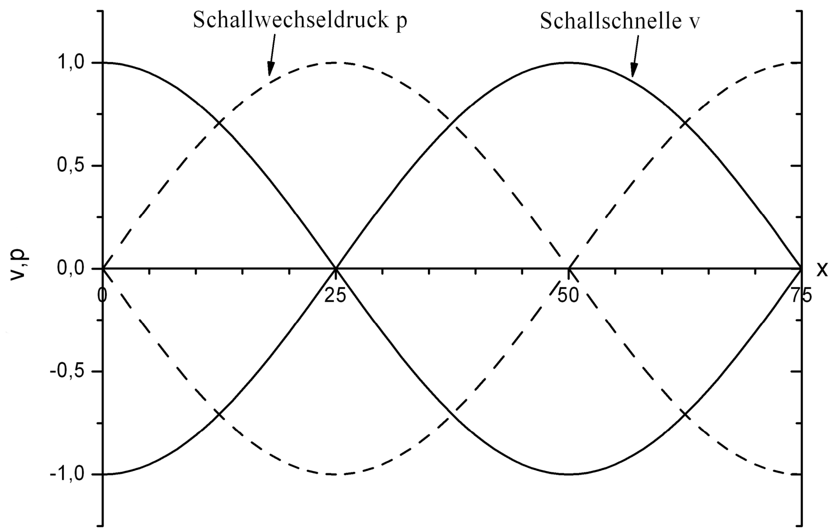


**Fig. 1**: Progression of sound particle velocity *v* and sound pressure *p*

In order to achieve the best possible resonance, the plastic plugs are in a placed at the location of maximum pressure. If this is done, a loud standing wave forms in the Kundt tube. When a sound wave collides perpendicularly with a wall, the resulting sound field, comprised from the values of the incident and reflected waves, is formed in front of the wall. The reflection factor is defined as the ratio of the incident and reflected pressure change:

$$r = \frac{p_r}{p_e}$$

Since the individual pressures $p_r$ and $p_e$ cannot be measured separately, this equation cannot be used experimentally to determine *r*. For most applications, it is enough if you know the amount of the reflection factor. This can be expressed with the amplitudes:

$$|r| = \frac{\hat{p}_r}{\hat{p}_e}$$

A pressure maximum occurs where incident and reflected waves overlap in phase:

$$\hat{p}_{max} = \hat{p}_e + \hat{p}_r$$

Accordingly, a pressure minimum occurs when they overlap in opposite phase:

$$\hat{p}_{min} = \hat{p}_e - \hat{p}_r$$

Which means:

$$|r| = \frac{\hat{p}_{max} - \hat{p}_{min}}{\hat{p}_{max} + \hat{p}_{min}}$$

In **Fig. 1**, the plugs were ideally acoustically hard, meaning $r = 1$. The following general distinctions can be made:

| | | |
|---|---|---|
| $r = +1$ | : | ideally acoustically hard (closed tube end) |
| $r > 0$ | : | acoustically hard |
| $r = 0$ | : | no reflection (complete absorption or horn end) |
| $r < 0$ | : | acoustically soft |
| $r = -1$ | : | ideally acoustically soft (open tube end) |

In an ideal sound-absorbent isolation (open end), the end of the tube is at a location of minimum pressure. Outside of the pipe, a spherical wave continues.

If the reflection factor is not equal to 1, the sharp pressure sounds are diminished and the pipe end is not in a place minimum or maximum pressure.

## 3 Tasks

**Note**: Throughout the experiment, only a single, fixed frequency is used!

1. Creating a standing acoustic wave.
   Set the pipe length by moving the speaker so that the plug is located in a place of maximum pressure. The plastic plugs are used and the microphone inserted into it so far that it is flush with the surface of the plug. By moving the loudspeaker, the largest possible display value will be set on the digital voltmeter (DVM). The DVM (voltage) indicates the effective value of the alternating sound pressure.
   **Take note!** Select the sensitivity of the microphone and the amplitude of the frequency generator so that measurements are within a 2 V range. At higher voltages the built-in amplifier is overridden, and the measured values are distorted.
2. Measurement of the sound field.
   For this purpose, the microphone is pushed into the tube in 5 mm and the displayed value from the DVM noted. The measurement is carried out using both the plastic and foam plugs and the open end of the tube, where each change in the length of the tube

must be optimised by re-adjustment.
The frequency of the sound wave can be determined using the following equation, with $c_0$ = 331.6 m/s and $T_0$ = 273.15 K.

$$c = c_0 \cdot \sqrt{\frac{T}{T_0}}$$

Be aware that digital thermometers display temperatures in Celsius. For this, only the measurement of the plastic plugs is evaluated.

3 Determining the speed of sound in $CO_2$.
The plug is removed and the gas replaced. The $CO_2$ is left for about 30 seconds to slowly flow into the pipe. It can now be assumed that almost only $CO_2$ is in the pipe. The plastic plug is inserted, and after re-adjustment of the speaker, the measurement from step 2 is repeated (only plastic plugs). The frequency may not be changed during each test.
Calculate the speed of sound in $CO_2$ by using the frequency determined from part 2 and compare with results from the text book.

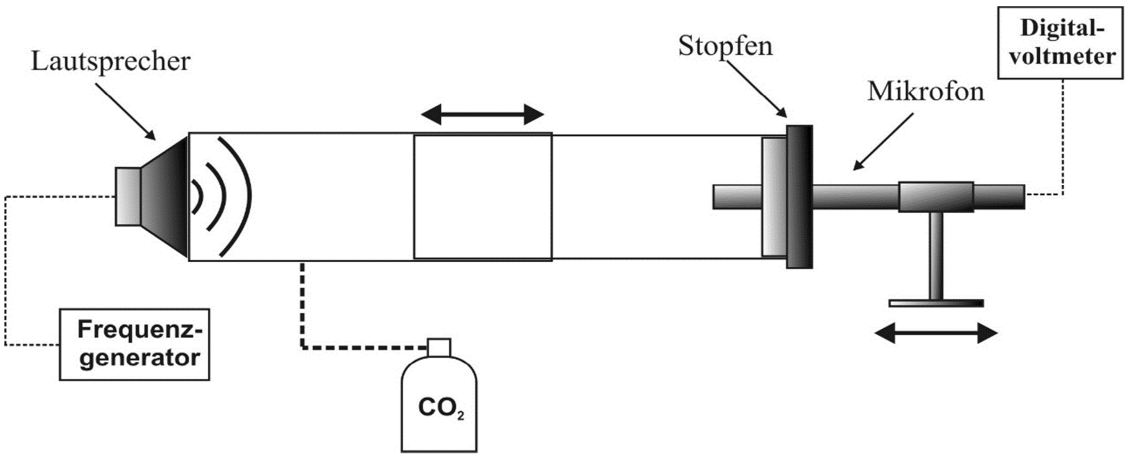


**Fig. 2**: Schematic experiment layout

## 4 Producing Experimental Protocols

- Introduction (incentive, trial objective)
- Theoretical basics (introduction of all plausible measures, as well as the derivation of all formulas used, the answers to the 5 questions of the questionnaire must be found in the text)
- Implementation (description of the structure, sketch, description of tasks)
- Results (measured value tables, graphs)
- Summary / Conclusion (Review the results, compare with text book values and settings, possible sources of error)

## 5 Suggestions for Evaluation

1 Measurement with plastic or metal plugs
  - Determine the wavelength (also the application of the distance between minima and maxima), specify errors
  - Calculate *c* using Eq. 6
  - Calculate the frequency and respective error (error propagation)
  - Calculate the reflection factor using Eq. 5

2 Measurement of the foam plug and open end
  - Calculate the reflection factor using Eq. 5

3 Measurement of $CO_2$
  - Determine the wavelength (also the application of the distance between minima and maxima), specify errors
  - Calculate *c* using the frequency (and error) result from Eq. 1, (error propagation)

Graphs are required for all measurement!