IM5

Modul Mechanics

Doppler Effect

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1.1 Preliminary Questions

- Name some applications in which the Doppler effect may be beneficial.
- How can one explain the Doppler effect?
- Where does the name RADAR come from and how does it work?
- How does an ultrasonic transducer function?
- What is sound (or acoustic noise)?
- What is the speed of sound? What is the relationship between it, the frequency ν, and the wavelength λ?
- What is light?
- What is ultrasound?

1.2 Theory

1.2.1 The acoustic Doppler-Effect

The phenomenon of the acoustic Doppler effect is something we frequently encounter in everyday life. The known example is the siren of an emergency vehicle that sounds higher when the vehicle is approaching the observer. It sounds lower when the vehicle is far away from the observer. When the vehicle moves past the observer, the pitch changes at the moment of driving by. Similarly, the pitch behaves dormant when the source moves away relative to the observer.
Although the acoustic Doppler effect is only treated in the following way, the theory is generally applicable to any wave generator. As in sound waves, contrast to electromagnetic waves, they can only propagate in a medium, the acoustic Doppler effect does not emerge in a vacuum. In the vacuum, whereas the relativistic Doppler effect is observed, which is due to the fact that the electromagnetic waves are at a finite speed, the speed of light spreads.

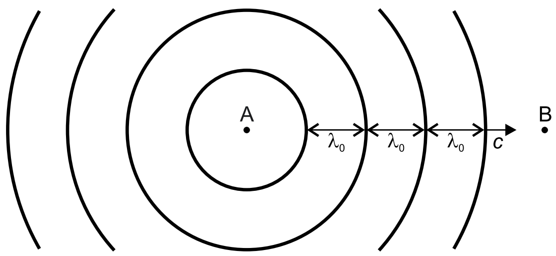

Figure 1.1: Sound propagation in a still sound source and a stationary observer.

Now, first consider the case where the sound source A and observer B relative to the propagation medium rests, see Figure 1.1. The result from the sound source A dies down all λ_0 the distance and approaching the speed of sound:

$$c = \lambda_0 \nu_0$$

the observer B until after the time:

$$t_0 = \frac{1}{f_0}$$

reach the observer. Now, the sound source A moves with the velocity v relative to the propagation medium and stationary observer B (see Fig. 1.2),

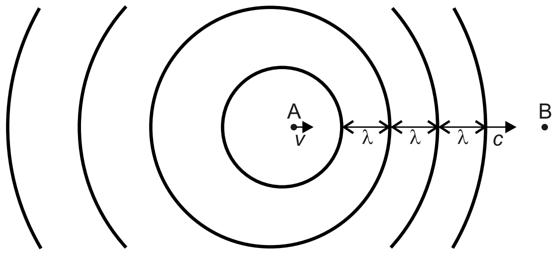

Figure 1.2: Sound propagation moving in a sound source and a stationary observer.

so shall the source during an oscillation period t_0 the distance

$$s = v \cdot t_0$$

is covered. Thus, the distance between the previous and new emerging wavefront from $v \cdot t_0$ is smaller than previously, namely

$$\lambda = \lambda_0 - v \cdot t_0$$

The wave fronts propagate at the speed c and reaches the observer after the time

$$t = \frac{\lambda}{c} = t_0 \left(1 - \frac{v}{c}\right)$$

The resting observer B listens to the moving sound source, and consequently the frequency

$$\nu = \frac{1}{t} = \frac{\nu_0}{1 - \frac{v}{c}}. \tag{1.1}$$

Now, the sound source does not move, but the observer does with velocity v relative to the propagation medium static sound source (see Fig. 1.3).

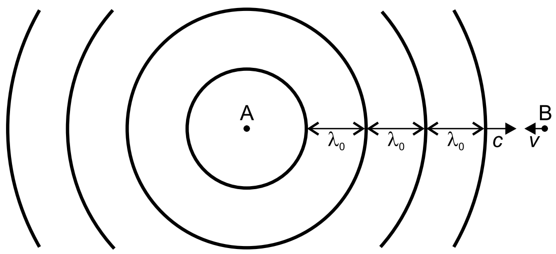

Figure 1.3: Sound propagation in a still sound source and a moving observer.

so the distance between the wave fronts is again λ_0 the original value. These then propagate in the medium with the velocity c and now reach the observation eighth but already in the time interval

$$t = \frac{\lambda_0}{c+v} = \frac{t_0}{1+\frac{v}{c}}$$

Therefore, the moving observer hears the dormant sound source with the frequency:

$$\nu = \frac{1}{t} = \nu_0 \left(1 + \frac{v}{c}\right) \tag{1.2}$$

Equations (1.1) und (1.2) provide for large velocities v different outcomes, and the difference can be neglected at low speeds. The frequency change

$$\Delta\nu = \nu - \nu_0 = \nu_0 \frac{v}{c}$$

is then proportional to the speed v. Equations (1.1) and (1.2) can also be combined in an equation, the observer frequency ν_B perceived, which describes when the transmitter and the receiver are in motion in the medium relative to the speed v_S, v_B, respectively.

- Transmitter and receiver are moving toward each other:

$$\nu_B = \nu_S \frac{c + v_B}{c - v_S} \tag{1.3}$$

- Transmitter and receiver are moving away from one another:

$$\nu_B = \nu_S \frac{c - v_B}{c + v_S} \tag{1.4}$$

With equations (1.3) and (1.4), it can also now be formulated a very general form of the observations of the perceived frequency:

$$\nu_B = \nu_S \left(\frac{c \pm v_B}{c \mp v_S}\right) \tag{1.5}$$

wherein the upper (lower) sign operation applies when approaching an observer and transmitter (leave).

1.3 Experiment

1.3.1 Equipment

Components	Number
Ultrasonic transducer 40kHz	2
Generator 40kHz	1
AC Amplifier	1
Measuring car with electric drive	1
Precision metal rail 1m	2
Track connector	1
Track feet	2
Digital counters	1
Two channel oscilloscope	1
Stopwatch	1
Base	2
Stand rod 25cm	1
Stand rod 47cm	1
Sleeve with ring	1
Shielded connection cables	1
Couplings	6
Measuring cable BNC/4mm	1
Experiment cable	4

1.3.2 Experimental Setup and Adjustment

Fundamental Setup

- Ultrasonic transducer (c) with velcro longitudinally on the measuring car with an electric drive fixed and set the measuring car set to the metal rail.
- Shielded cable connection via the coupling plug is connected to the cable pair of ultrasonic converter, mount at the appropriate length, looped through the ring (d), and the free end of the output (e) connected to the generator.
- Ultrasonic transducer (f) connected to the input of the AC amplifier and aligned such that both ultrasonic transducers are facing in the same height.

Adjusting the Resonance Frequency

- Put the generator on continuous operation and put the AC amplifier to "$\sim$".
- Turn both on and wait 15 minutes until a stable operating condition is reached.
- To avoid interferences from reflections between transducer and receiver, wrap both with a strip of paper and let it overlap approx. 10 cm.
- Feed in the output of the AC amplifier for amplifying medium via the BNC measuring cable in the oscilloscope feed (see Fig. 1.4).
- Observe the output signal with an oscilloscope and improve the alignment of the two ultra sound transducers.

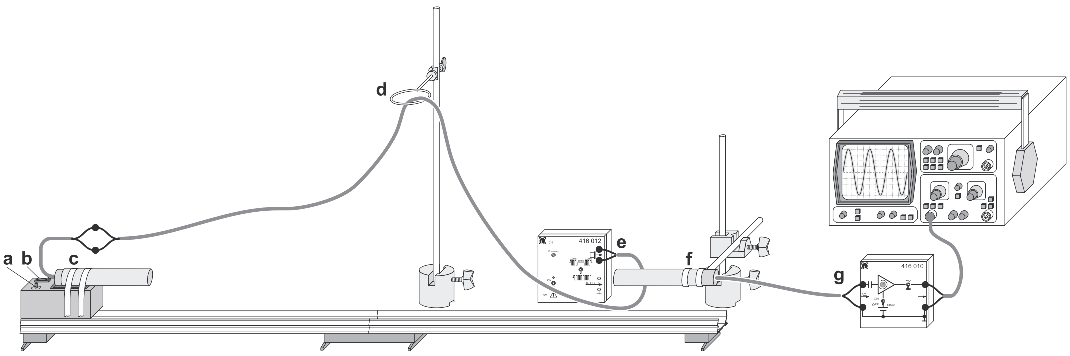

Figure 1.4: Setup for adjusting the resonance frequency

- The frequency generator is adjusted so that is has the output maximum amplitude (resonance frequency).
- With the gain of the AC amplifier, the amplitude of the output signal at maximum painter distance of the trolley as Set to about 0.7V.

Measuring the frequency of ultrasonic transducer

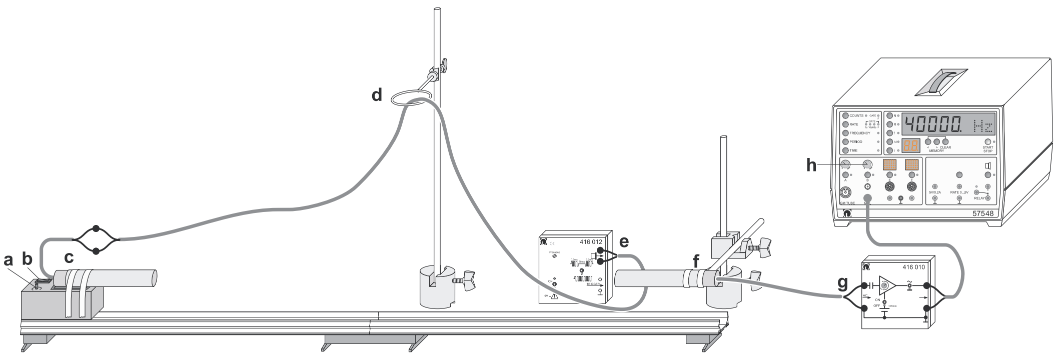

Figure 1.5: Experimental setup for investigating the Doppler effect in a moving sound source

- Switch on the digital counter, feed in the output of the AC amplifier via the BNC measuring cable in the input feed B (see Fig. 1.5) and press the B button.
- Press the frequency button and select units in Hz.
- Put the input of input B rotary potentiometer (h) at 0.7V.

Implementation

- Adjust the velocity v of the measuring car with potentiometer (a).
- Turn on the drive motor with the three-position switch (b), let the measuring car go to determine the rate of the measuring distance $\Delta s = 1m$ and record the required time Δt with the counting device and integrated with the stopwatch three times.

- Switch the drive motor off with the three-position switch with the START/STOP button of the digital start counter measuring the frequency ν_0 and after about 1s press the button again to end.
- Press the three-position switch, let the measuring car go with the previously determined speed to the "right" and start with the START/STOP button of the stopwatch and measure the frequency ν and after a few seconds, press the button again.
- Switch the drive motor off with the three-position switch and determine the rest frequency ν_0 again.
- Press the three-position switch, let the measuring car go at the same speed to the "left" and measure the frequency ν and record it.
- Move the measuring car "right" and "left" three times and repeat the frequency measurement.
- First set smaller speeds of the measuring car and measure the velocity v and then the frequency measurements to the "right" and "left" of the moving measuring car.
- Repeat the measurements for a total of five other velocities v.
- Repeat the same measurement with stationary stations and mobile receivers with the ultrasonic transducer on the measuring car with the connecting cable to the input of the AC amplifier and the connected ultrasonic transducer to the output of the generator is connected.

1.3.3 Tasks for Evaluation

- Determine the mean, standard deviation and the standard deviation of the mean of the velocity, and the shifted frequency ν for each measurement series and both directions.
- Show in a a graph the frequency variation $\Delta\nu$ versus the velocity v of the measuring car.
- Check for both experiments the relation between the frequency change and velocity.
- How does the frequency change $\Delta\nu$ depend on the velocity of the transmitter?
- Determine from the graph the value for the velocity of sound and compare it with the literature value for the corresponding ambient temperature.

1.4 Literature

- D. Meschede, "*Gerthsen Physik*", Springer Verlag