Acoustic Doppler effect with universal counter

(Item No.: P2150405)

Curricular Relevance
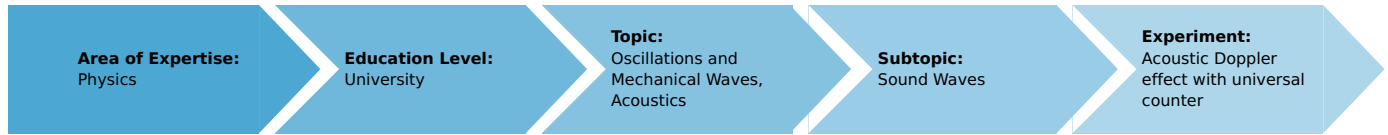
| Area of Expertise: Physics | Education Level: University | Topic: Oscillations and Mechanical Waves, Acoustics | Subtopic: Sound Waves | Experiment: Acoustic Doppler effect with universal counter |

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	10 Minutes	10 Minutes	2 Students

Additional Requirements:	Experiment Variations:

Keywords:
Wave propagation, Doppler shift of frequency

Introduction

Overview

If an emitter of sound or a detector is set into motion relative to the medium of propagation, the frequency of the waves that are emitted or detected is shifted due to the Doppler Effect.
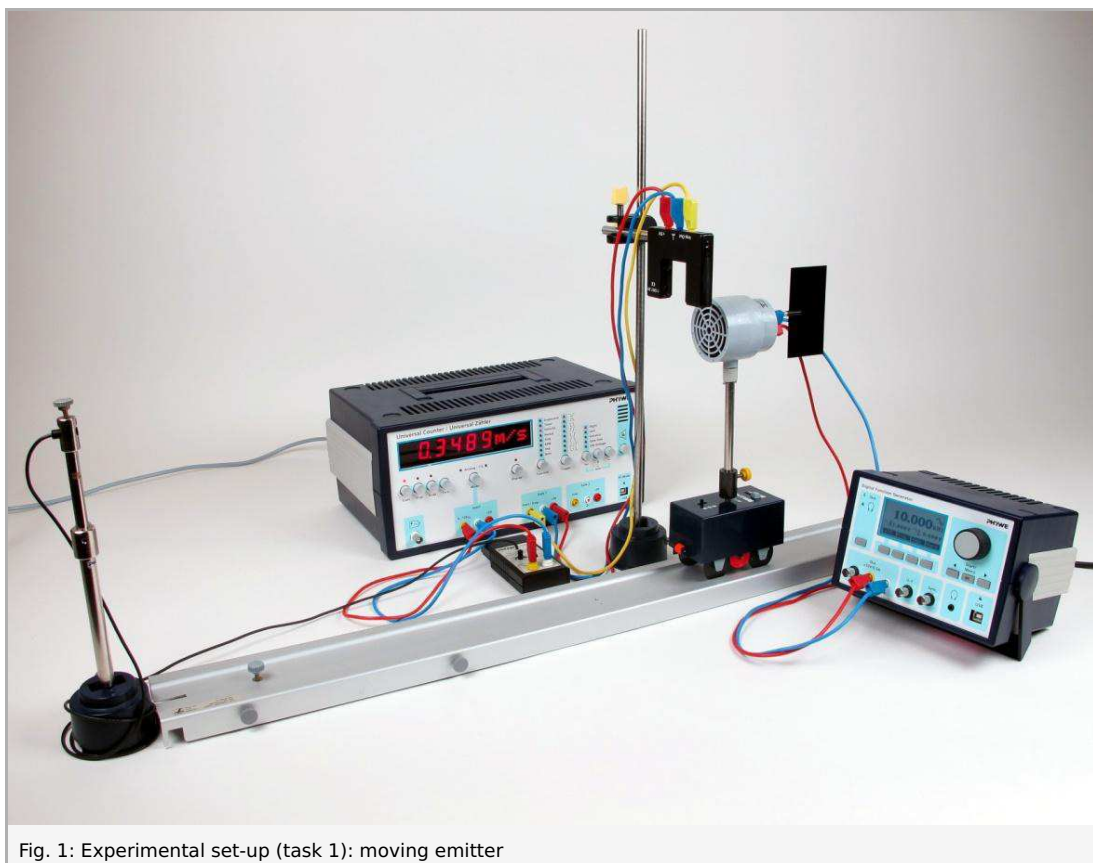

Fig. 1: Experimental set-up (task 1): moving emitter

Equipment

Position No.	Material	Order No.	Quantity
1	Universal Counter	13601-99	1
2	Measuring microphone with amplifier	03543-00	1
3	Flat cell battery, 9 V	07496-10	1
4	PHYWE Digital Function Generator, USB	13654-99	1
5	Light barrier, compact	11207-20	1
6	Car, motor driven	11061-00	1
7	Attachment for car	11061-02	1
8	Track, l 900 mm	11606-00	1
9	Battery cell, 1.5 V, baby size, type C	07922-01	2
10	Boss head	02043-00	1
11	Loudspeaker / Sound head, 8 ohms	03524-01	1
12	Holder for two electrodes	45284-01	1
13	Screen with plug, l 100 mm	11202-03	1
14	Barrel base PHYWE	02006-55	2
15	Support rod, stainless steel, l = 600 mm, d = 10 mm	02037-00	1
16	Support	09906-00	1
17	Connecting cord, 32 A, 500 mm, red	07361-01	1
18	Connecting cord, 32 A, 750 mm, red	07362-01	2
19	Connecting cord, 32 A, 500 mm, blue	07361-04	1
20	Connecting cord, 32 A, 750 mm, blue	07362-04	2
21	Connecting cord, 32 A, 750 mm, yellow	07362-02	1
22	Stand tube	02060-00	1

Tasks

1. Measure the Doppler shift for varying frequencies and velocities for a moving sound emitter. Compare the measurements with the values predicted by theory and validate equation (4).

2. Measure the Doppler shift for varying frequencies and velocities for a moving detector. Compare the measurements with the values predicted by theory and validate equation (6).

Set-up and procedure

Set-up

Task 1
The experiment for the resting detector and the moving source is set up as shown in figures 1 and 2. The sound head and the microphone have to be adjusted to the same height. Adjust the screen on the sound head so that it passes the light barrier without impacting the car's progress.
The sound head is connected to the output of the digital function generator. The microphone is connect-ed to the input of the universal counter. Connect the light barrier to the universal counter as shown in Fig. 1.
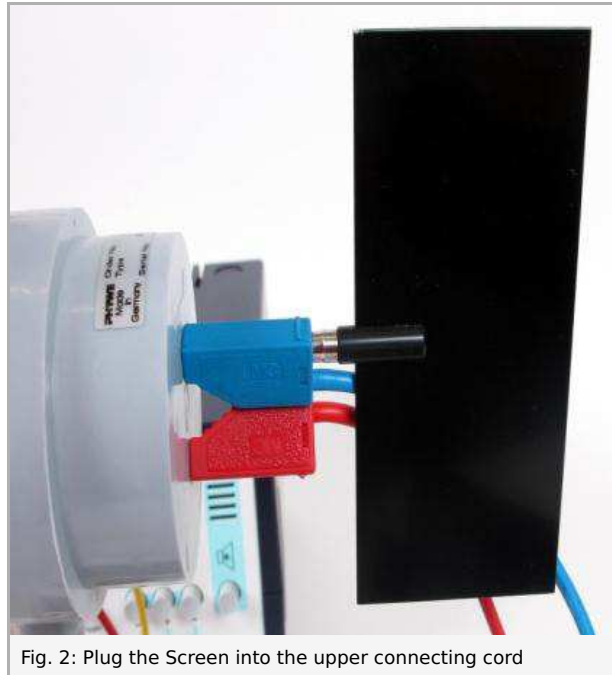

Fig. 2: Plug the Screen into the upper connecting cord

Task 2
The experiment for the resting source and the moving detector is set up as shown in Fig. 3. The sound head and the microphone have to be adjusted to the same height. Adjust the screen on the car so that it passes the light barrier without impacting the car's progress. Connections of microphone, sound head and light barrier is as in Task 1.
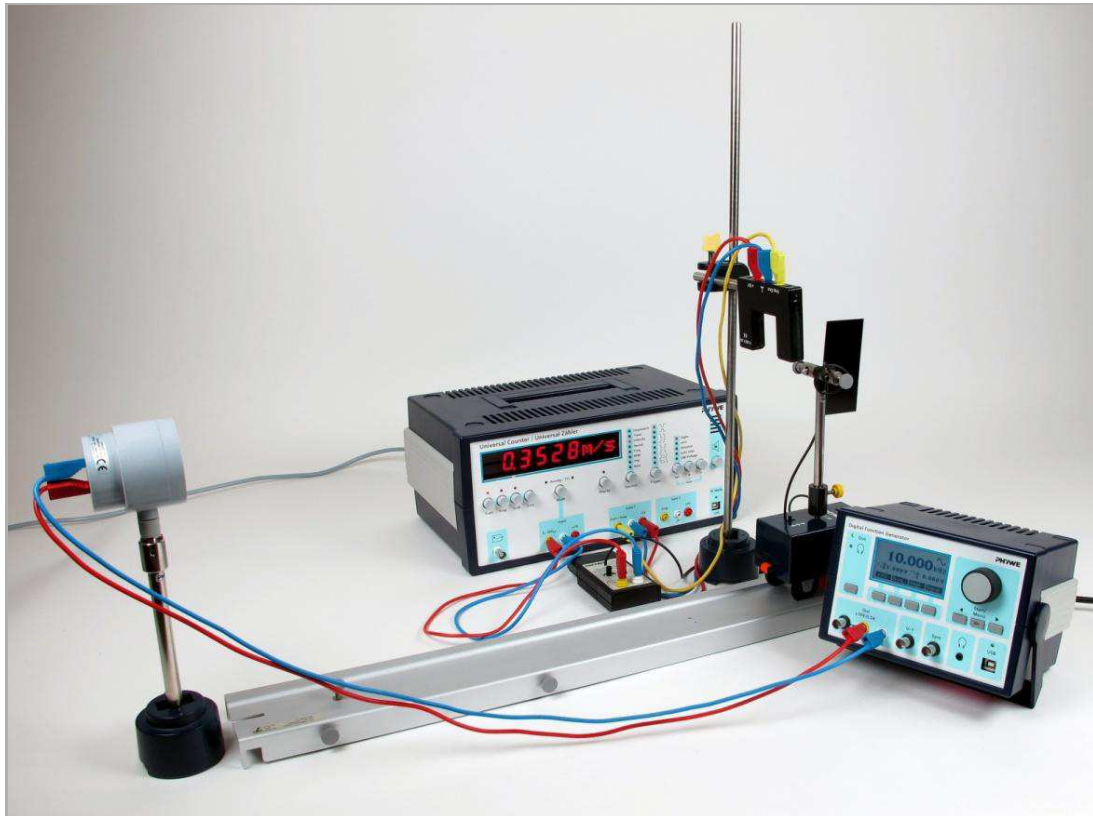
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Fig. 3: Experimental set-up (task 2): moving detector

Procedure

Task 1

For at least three different velocities between 0.06 m/s and 0.16 m/s and five different frequencies be-tween 5 kHz and 10 kHz measure the Doppler shifted and original frequency.
The settings of the counter have to be chosen as follows:

- velocity measurement
    - function: velocity
    - trigger: ⊔
    - distance: 50 mm
- frequency measurement
    - mode: analog
    - function: frequency

The settings of the digital function generator have to be chosen as follows:

- frequency: 5 kHz... 15 kHz
- amplitude: 1 V
- signal: sinus

At first, the car's velocity has to be determined. Set the car's velocity controller to an intermediate position, and set the direction in such a manner that the car moves away from the microphone. Choose the car's starting point carefully so that the car's speed is constant while passing the light barrier i.e. that it is no longer accelerating. Perform at least five measurements to determine the average velocity of the car.
After that, choose the appropriate settings of the digital function generator and change the settings of the universal counter in order to measure the shifted frequency. Use the Start and Stop buttons to begin and end the measurement. With the Hold button fix a measured value during the pass of the light barrier. For each original frequency perform at least five measurements and note down the measured frequency.
Repeat the procedure (also the velocity measurement!) for the case of the emitter moving towards the detector.
Perform the measurements for at least three different velocities.

Task 2

First determine the velocity of the car as described in Task 1.
Afterwards choose the frequency and change the settings of the universal counter in order to measure the frequency. For each frequency record five values with both the loud speaker and the microphone at rest as well as for the moving microphone.
Perform the procedure for both directions of movement and at least three different velocities.

Notes: If the universal counter does not measure the frequency despite clearly audible tone, it may be necessary to adapt the output voltage of the microphone amplifier.
During the measurement no background noise may occur, since it would also be registered by the microphone falsifying the frequency measurements.

If the car velocity is slowing down progressively although the velocity controller has not been adjusted, the battery might be low and should be changed. The fact that the car's forward and backward velocities are not identical for the same velocity controller setting is normal and due to the type of motor used in the car.

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Theory and evaluation

Theory

Considering the Doppler effect one has to distinguish two cases:
i) the emitter is moving relatively to the detector (compare to Task 1) and
ii) the detector is moving relatively to the emitter (compare to Task 2).
For the propagation of sound in general

$$c = f \cdot \lambda \tag{1}$$

is valid where c is the velocity of sound in the medium, f is the frequency and λ the wavelength.

Task 1
In the first case, the source is moving while emitting sound waves. So, in the time between two wave fronts, the emitter travels distance s with velocity v, with $T = \frac{1}{f}$ being the period of the sound wave.

$$s = v \cdot T \tag{2}$$

Accordingly, the wavelength (the distance between two wave fronts) is shortened by that distance and one obtains the new wavelength

$$\lambda' = c_0 \cdot T \pm v \cdot T \tag{3}$$

There $c_0 \cdot T$ is the distance the first wave front has travelled and the formula is valid for an emitter moving in direction of the detector (−) and in the opposite direction (+) respectively.
Inserting relation (1) and simplifying one obtains the expression for the shifted frequency of the moving emitter

$$f' = f(1 \pm \tfrac{v}{c})^{-1} \tag{4}$$

Task 2
In the second case, the detector is moving with velocity v between detecting subsequent wave fronts. So the velocity of the detector adds to (subtracts from) the velocity of the detector if the detector is moving towards (away from) the emitter. One obtains for the detected frequency:

$$f' = \tfrac{c \pm v}{\lambda} \tag{5}$$

Insertion of (1) and simplification results into

$$f' = f(1 \pm \tfrac{v}{c} \tag{6}$$

If both the emitter and the detector are moving, one obtains for the shifted frequency the following expression with D and E denoting the detector and emitter respectively:

$$f' = f(1 \pm \tfrac{v_D}{c} / 1 \pm \tfrac{v_E}{c}) \tag{7}$$

Results and evaluation

In the following the evaluation of the obtained values is described with the help of example values. Your results may vary from those presented here.

	v_- (m/s)	Δf (Hz)	Δf (Hz)	Δf (Hz)	v_+ (m/s)	f (kHz)	f (kHz)	f (kHz)
f_0		399.95	999.95	4999.95		5.0	10.0	12.0
1	0.140	-0.23	-0.45	-2.03	0.147	2.11	4.5	5.6
2	0.138	-0.19	-0.23	-1.96	0.152	2.01	4.3	5.0
3	0.137	-0.10	-0.15	-2.12	0.150	2.00	4.9	5.1
4	0.139	-0.18	-0.48	-2.17	0.158	1.88	4.1	5.3
5	0.138	-0.15		-2.05	0.156	2.09	4.3	5.3
mean	0.138	-0.17	-0.33	-2.07	0.153	2.02	4.5	5.3
std. dev.	0.001	0.04	0.14	0.07	0.004	0.07	0.3	0.2

Table 1 shows example values for Task 2. The first row of values shows the frequencies with both emitter and detector at rest. The following five rows give the measured frequency shifts. The last two rows give the mean values and the standard deviation respectively.

As can be clearly seen from the table the Doppler shift is very small for low frequencies which makes it hard to measure, as the error is of the same magnitude. That is why the experiment should be done with frequencies of 5 kHz and higher.

Figures 4 and 5 show the results in comparison with calculated values with $c = 330$ m/s. The experiment yields very good results —even for very low frequencies.
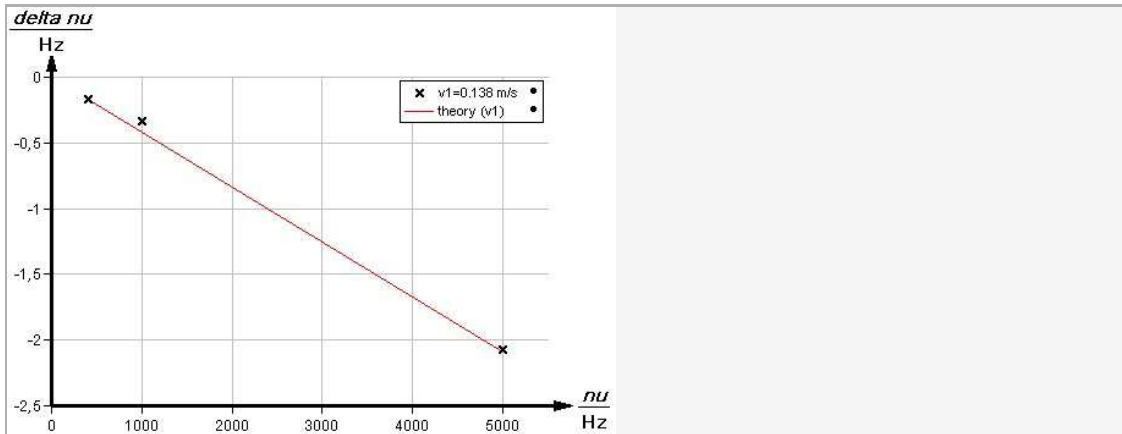

Fig. 4: Comparison of the measured values with calculation after eq. (6) for a detector moving away from the emitter.
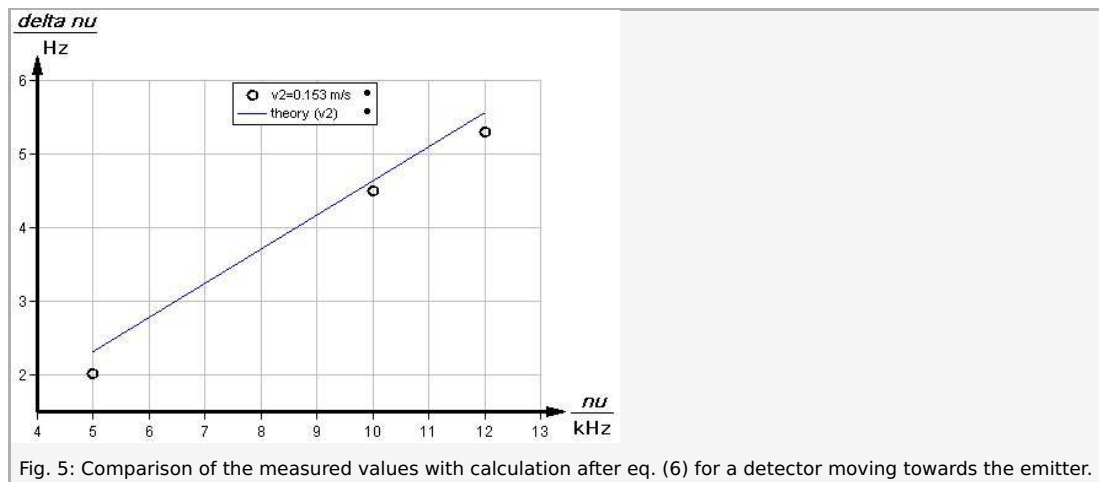

Fig. 5: Comparison of the measured values with calculation after eq. (6) for a detector moving towards the emitter.

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