UNIWERSYTET ŚLĄSKI
WYDZIAŁ NAUK ŚCISŁYCH I TECHNICZNYCH

I PHYSICS LABORATORY

EXERCISE

Acoustic Doppler Effect

Prepared by:
dr hab. Małgorzata Karolus, prof. UŚ

MechBio- Innowacyjne Nauczanie Problemowe i Technologie dla
Poprawy jakości Kształcenia w obszarze GZM został
dofinansowany przez Górnośląsko-Zagłębiowską Metropolię
w ramach Programu „Metropolitalny Fundusz Wspierania Nauki"

Topics for the introductory test

- Elastic waves, quantities characterizing wave motion.
- Sound wave propagation - reflection, refraction, absorption.
- The Doppler effect.
- The mechanism of the Doppler effect for sound waves.
- The mechanism of the Doppler effect for light waves (color shift).
- The formula for frequency change for sound.
- Examples of applications.

Equipment

- PHYWE multimeter (1)
- PHYWE generator (2)
- Car (3) with screen (4)
- Car track (5) with gate (6)
- Microphone
- Detector
- Cables
- Multimeter and generator manual

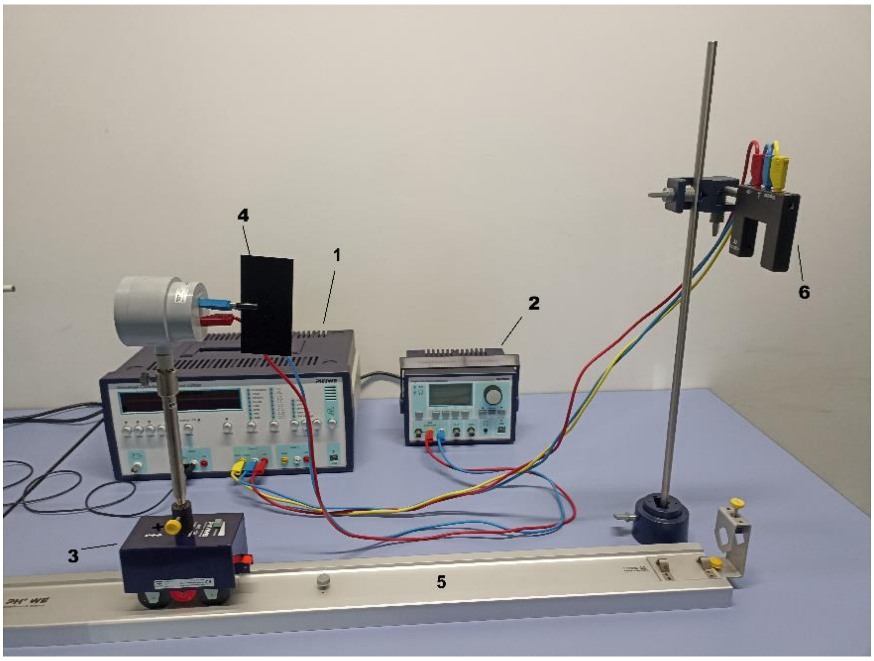

Fig. 1. Measuring set

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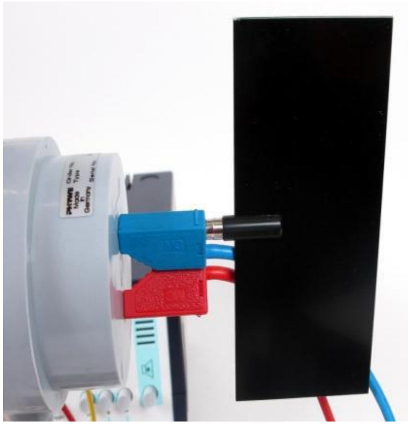

Fig. 2. Connecting the screen to the upper connection cable

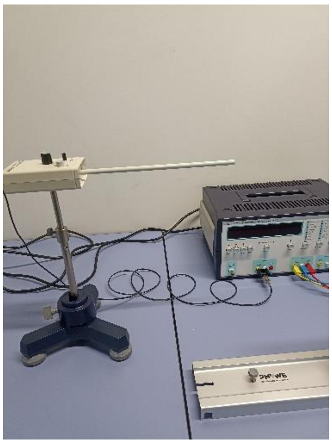

Fig. 3. Connecting the microphone to the universal counter

Fig. 4. Multimeter

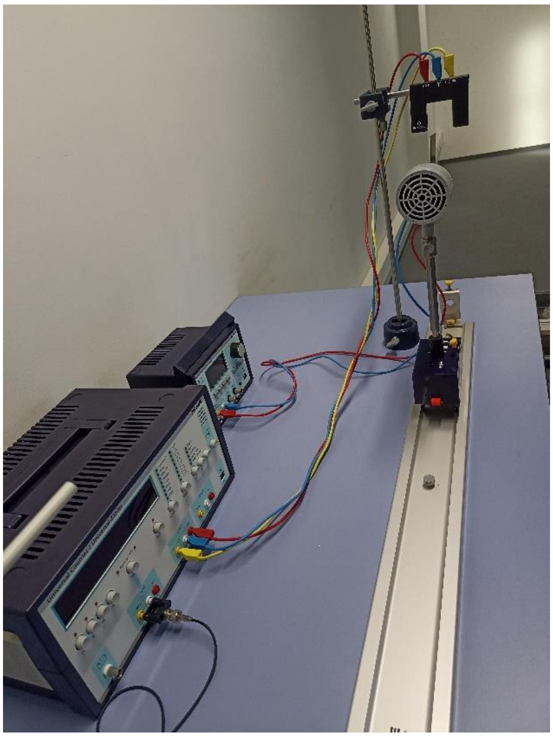

Fig. 5. Connection of the measuring system elements

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Equations

When considering the Doppler effect, we must distinguish between two cases: when the emitter moves relative to the detector (i) and when the detector moves relative to the emitter (ii).

For sound propagation in general, the following equation holds:

$$c = f \cdot \lambda, \qquad (1)$$

where *c* is the speed of sound in the medium, *f* is the frequency and λ the wavelength.

In the first case (i), the source moves, emitting sound waves. Thus, in the time between two wave fronts, the emitter travels a distance *s* at a speed *v*, where $T = 1/f$ is the period of the sound wave:

$$s = v \cdot T. \qquad (2)$$

Therefore, the wavelength (distance between the two wave fronts) is shortened by this distance, and a new wavelength is obtained:

$$\lambda' = c_0 \cdot T \pm v \cdot T. \qquad (3)$$

This is the wavelength that the first wave front has traveled, and the pattern is valid for the emitter moving towards the detector (−) and away from it (+).

By introducing the relation (1) and simplifying it, we obtain the expression for the shifted frequency of the moving emitter:

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

In the second case (ii), the detector moves with velocity *v* between successive wavefront positions. Thus, the detector velocity is added (subtracted) to the detector velocity if the detector moves towards (or away from) the emitter. For the detected frequency, we have:

$$f' = (c + v)/\lambda \qquad (5)$$

Inserting (1) and simplifying the results leads to:

$$f' = f(1 \pm v/c) \qquad (6)$$

If both the emitter and the detector are moving, we get the following expression for the shifted frequency, where *D* and *E* denote the detector and emitter, respectively:

$$f' = f\left(\frac{1 \pm v_D/c}{1 \pm v_E/c}\right) \qquad (7)$$

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Performing the exercise

1. Read the instruction manual for your multimeter and generator.

> *Select the meter settings as follows:*
> *Speed measurement - function: speed*
> *Trigger:*
> *Distance: 50 mm*
>
> *Frequency measurement - mode: analog; function: frequency*
> *Select the digital function generator settings as follows:*
> *Frequency: 5 kHz... 15 kHz*
> *Amplitude: 1 V*
> *Signal: sine*

2. Measurements for a static source (microphone) and a moving detector (car).

For at least three different velocities between 0.06 m/s and 0.16 m/s and five different frequencies between 5 kHz and 10 kHz, measure the Doppler-shifted frequency and the original frequency.

3. Connect the microphone, detector and gateway according to the diagram in Fig. 1.

- Set the detector and microphone at the same height.
- The connection of the screen to the detector is shown in Fig. 2.
- The connection of the microphone to the multimeter is shown in Fig. 3.
- The screen in the car should be adjusted so that it passes through the barrier (gate) without affecting the vehicle's operation.
- The detector is connected to the output of the digital function generator. The connection of the gate to the multimeter (Fig. 4) is shown in Fig. 5.

4. Determining the speed of the car.

- Take measurements for three different speed settings on the car's cruise control: minimum speed (v_1), intermediate speed (v_2), and maximum speed (v_3).
- Set the direction so that the car moves away from the microphone.
- Select the starting and ending points of the car's route and measure the distance (S).
- Measure the time it takes the car to travel the selected section of road for all three settings (T_1, T_2, T_3).
- Take at least five measurements to determine the car's average speed (v_1, v_2, v_3).

5. Select the appropriate digital function generator settings and change the universal counter settings to measure frequency. Use the *Start* and *Stop* buttons to begin and end the measurement. Use the *Hold* button to lock the measured value while the car passes through the frame.

6. Select three different frequencies, e.g. 500; 1000; 5000 Hz.

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7. For each selected starting frequency, take at least five measurements of the car's motion and record the measured ending frequency.

8. Repeat the procedure for at least three different car speeds.

Note:

- *If the multimeter does not measure frequency despite clearly audible sound, it may be necessary to adjust the microphone amplifier's output voltage.*
- *There should be no background noise during the measurement, as this would also be picked up by the microphone, distorting the frequency measurements.*
- *If the car's speed gradually decreases even though the cruise control has not been adjusted, the battery may be discharged and should be replaced. It is normal for the car's forward and reverse speeds to vary for the same cruise control setting and is due to the type of engine used in the car.*

Processing of results

1. Determine three different car speeds.
2. Determine three different initial frequencies.
3. For each of the three speeds, calculate the frequency change for three different initial frequencies using equation 6.
4. Calculate the mean values and standard deviation.
5. Present the results in a table.
6. Plot the relationship between the final and initial frequency changes on a graph and indicate any measurement errors.
7. Record your conclusions and comments regarding the experiment.

Literature

1. Halliday Dawid, Resnick Robert, Walker J., Fundamentals of Physics, John Wiley &Sons, Inc. 2007
2. Walker Jearl, Resnick Robert, Halliday David, Principles of physics: International student version, Wiley &Sons, Inc. 2011
3. J. Orear, Physics, MacMillan Publishing Company 1979

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