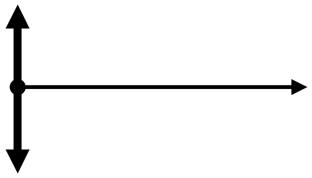
EUROPEAN UNION
MINISTRY OF EDUCATION, YOUTH AND SPORTS
OP Education for Competitivness
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

MECHANICAL WAVES

- Name the difference between mechanical and electromagnetic waves
- The source of the mechanical wave must ……………………… and it must be surrounded by the suitable medium, which contains …………………………… (not vacuum!) = “pružné prostředí”. The detector of the mechanical wave must contain some part, which ………………………………….
- Energy is transferred only, not mass!!! – give example

1. Types of mechanical waves and their sources

transverse



source propagation of the wave

longitudinal

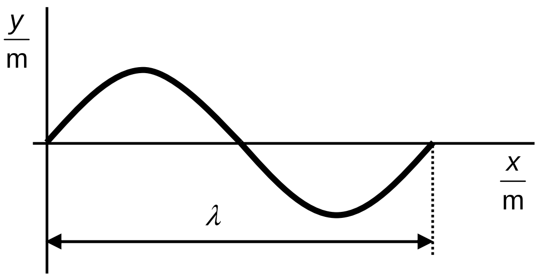
source propagation of the wave

rope, waves on water, …

slinky, SOUND

2. Wavelength (*λ*), frequency (*f*) and speed of the wave

wavelength
= the shortest distance between two points which vibrate with the same phase
= the distance travelled by the wave (in certain medium) during the time of one period (*T*)



Not time!

$(s = v \cdot t)$

$\lambda = v \cdot T$

$[\lambda] = \mathrm{m}$

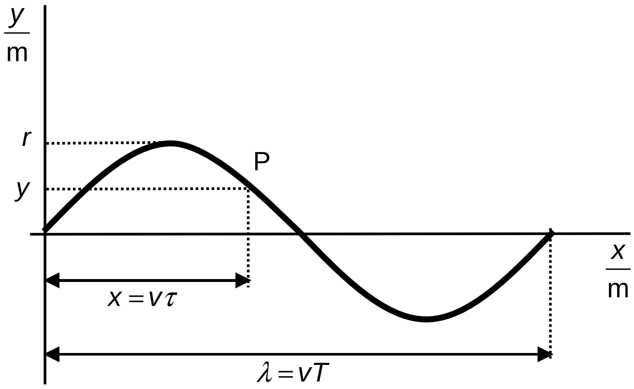
frequency = the number of cycles the source completes during one second $[f] = \mathrm{Hz} = \mathrm{s}^{-1}$

period = time taken for the source to complete one cycle $[T] = \mathrm{s}$

TENTO PROJEKT JE SPOLUFINANCOVÁN EVROPSKÝM SOCIÁLNÍM FONDEM A STÁTNÍM ROZPOČTEM ČESKÉ REPUBLIKY

3. Progressive wave equation

We will derive the equation for the displacement *y* of any point *P* of the medium through which the wave is propagating *t* seconds after the beginning of the vibration of the source



$y_P = f(t, x)$

source: $y = r\sin\omega t = r\sin(\frac{2\pi}{T}t)$

any point: $y_P = r\sin\omega(t-\tau) = r\sin\omega(t-\frac{x}{v}) = r\sin 2\pi(\frac{t}{T}-\frac{x}{vT}) =$

$= r\sin 2\pi(\frac{t}{T}-\frac{x}{\lambda})$

Questions:

1. We have a progressive wave of wavelength 32 cm, maximum displacement 5 cm and frequency of the source 2 Hz

a) Write the equation *y* = f(*x*, *t*)

b) Calculate the displacement of a point 8 cm from the source 0.5 s from the beginning of the motion

2. $y_P = 0.1\sin 2\pi(5t - 3.3x)$

State the maximum amplitude, wavelength and speed of the wave

3. $\lambda = 40\text{ cm}, f = 0.4\text{ Hz}, r = 5\text{ cm}$

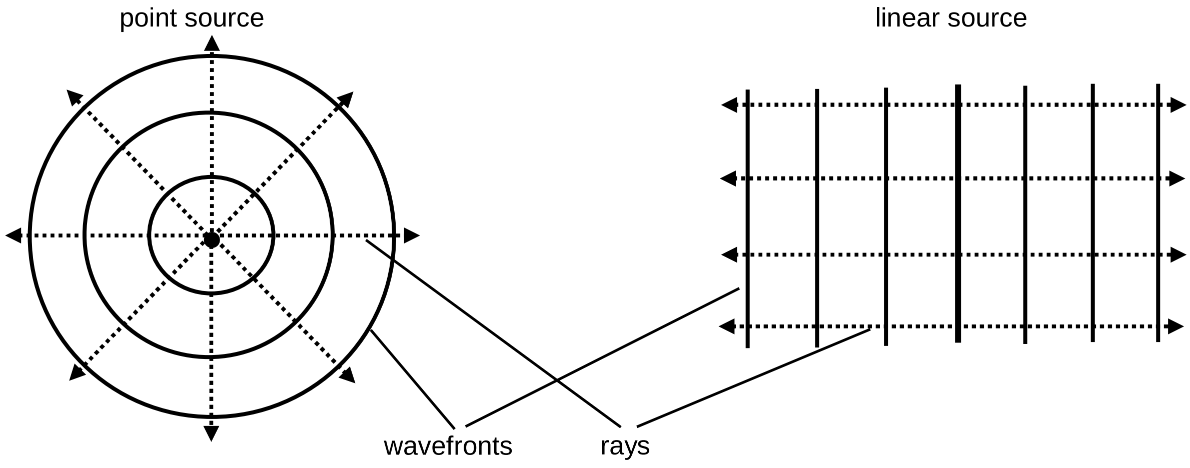
a) write the equation of the progressive wave

b) calculate the displacement of a point 45 cm from the source 12 s after the beginning of the wave motion

4. Transmission of mechanical waves

wavefronts and rays

rays represent the direction of propagation of the wave
wavefront is the set of points with the same phase –"where the wave appears at the same instant usually measured from the beginning of the vibration of the source"



Huygens' construction (about 1620-1695)

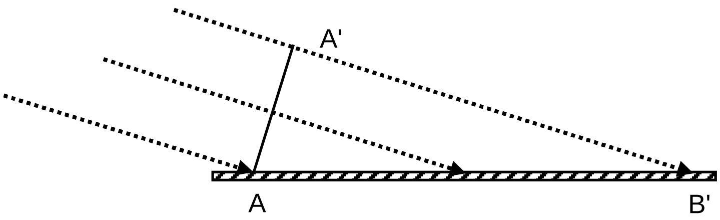
Each point of the wavefront can be regarded as a source of secondary wavelets, which spread out with the wave velocity. The new wavefront is the envelope of these wavelets.

Translation:

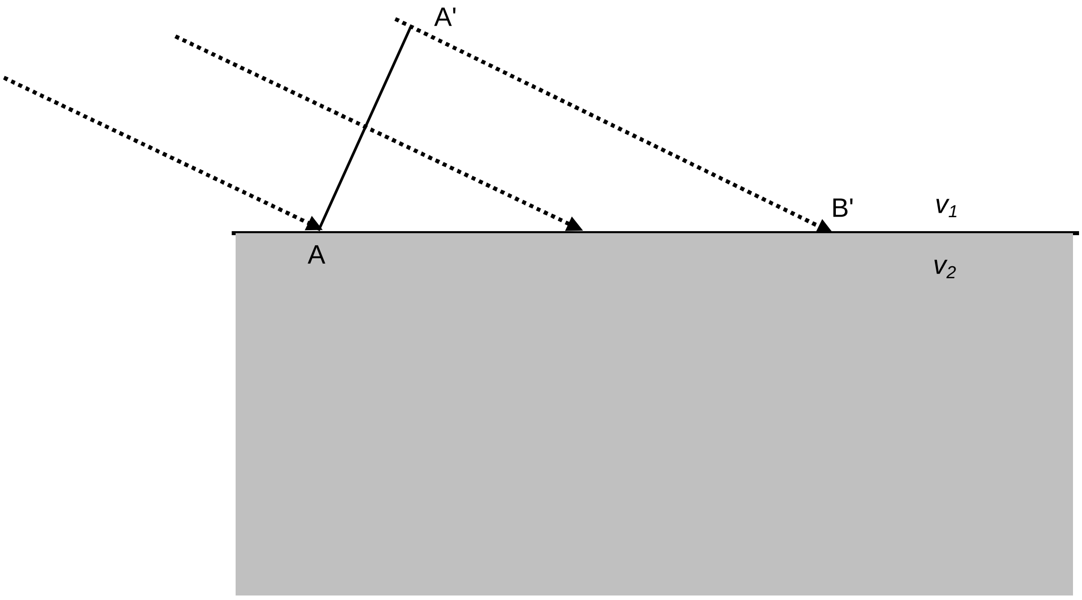
This principle is used to PROVE the laws of reflection and refraction and other wave phenomena, e.g.

DIFFRACTION

REFLECTION



REFRACTION



INTERFERENCE

takes place when 2 waves meet, result – superposition of the original waves

http://phet.colorado.edu/simulations/sims.php?sim=Wave_Interference

5. Standing(stationary) wave

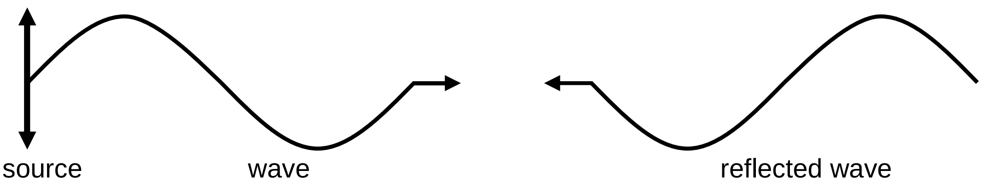
- **progressive wave** – „free wave motion in some medium“

energy (of the wave) is transferred further within the medium

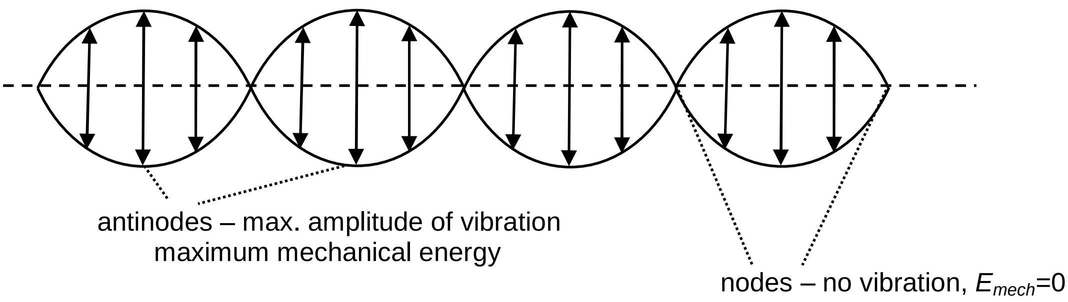
each point of the wave vibrates with the maximum displacement – as the source, assuming no wave energy converted into other types – ideal situation

- **standing wave** – when two progressive waves meet – interference pattern, one of the waves is usually reflected at the end of the medium

no energy is transferred further, just the kinetic energy of the vibrating points of the medium changes into potential energy and vice versa (this happens in progressive waves too)

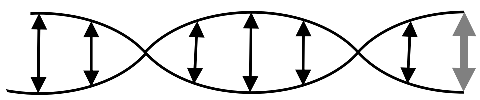


$\Rightarrow$
standing wave

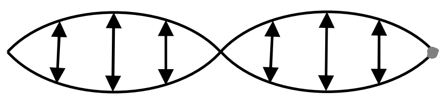


end of the medium can be

free (“free rope”) – antinode



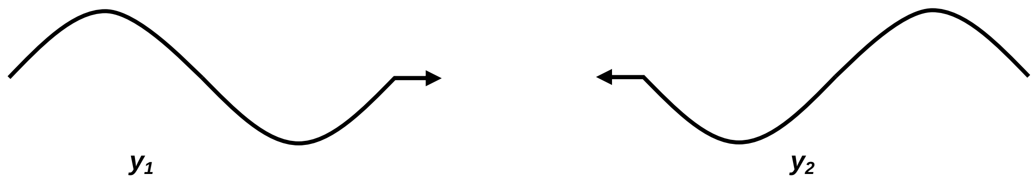
fixed (“tied rope”) - node



Standing wave equation

2 progressive waves coming against each other meet – stable pattern when they have the same (similar) maximum amplitude and frequency.

Q: Is the wavelength the same?



$$y_1 = r\sin(\omega t - \frac{2\pi}{T}\frac{x}{v})$$

$$y_2 = r\sin(\omega t + \frac{2\pi}{T}\frac{x}{v})$$

moving in opposite direction – ahead, not delayed

the resultant displacement of the point – the sum of the two waves

$$y_P = y_1 + y_2 = r\sin(\omega t + \frac{2\pi}{\lambda}x) + r\sin(\omega t - \frac{2\pi}{\lambda}x)$$

see the book of data:

$$\sin\alpha + \sin\beta = 2\sin\frac{\alpha+\beta}{2}\cos\frac{\alpha-\beta}{2}$$

label α, β in the previous equation:

$$y_P = r\sin(\omega t - \frac{2\pi}{\lambda}x) + r\sin(\omega t + \frac{2\pi}{\lambda}x) = 2r\sin\omega t\cos(-\frac{2\pi}{\lambda}x) = 2r\sin\omega t\cos\frac{2\pi}{\lambda}x$$

$$y_P = \underbrace{2r\cos\frac{2\pi}{\lambda}x}\,\underbrace{\sin\omega t}$$

"phase" of the vibration of the point – changes with time

maximum amplitude of **P = A**, depends on the position – distance from the source ***x,*** wavelength (speed of the wave and period of the source) and amplitude of vibration of the source

$$y_P = A\sin\omega t$$

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

antinode : *A=2r*
node: *A=0*

Questions:

4. Relate the statements for maximum amplitudes of the node and antinode to the general equation for *A.*

5. Take a standing wave, r = 2 cm, v = 3 cm·s^{-1}, f = 2 Hz
a) state the amplitude of antinodes
b) what is the maximum amplitude of the point 10 cm from the source
c) calculate the displacement of the point 12 s after the beginning of the wave motion

6. Strings and pipes, harmonics

Strings, pipes and other musical instruments produce many different frequencies. The lowest frequency (the longest wavelength) = the fundamental and it forms the pitch of the note. All the frequencies interfere with each other and according to that pattern we can distinguish between the instruments.

Pipes – air column vibrates, the speed of the wave is ....

Strings – the string vibrates as a source, the speed of the wave is controlled by the tension.

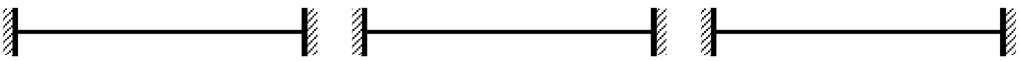
Use different resources and sketch the fundamental (first harmonic), first and second overtone (second and third harmonics) for the following instruments. Use the idea of reflection on the free and fixed end to find nodes and antinodes. For the pipes you can also find the relation between the length of the pipe and the frequency produced.

fundamental | 1st overtone | 2nd overtone

OPEN PIPE

CLOSED PIPE

STRING



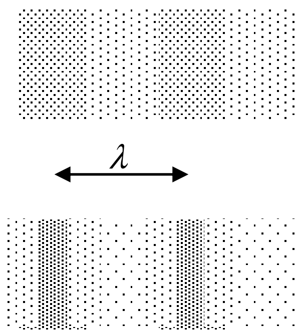
Sound

7. Sources, transmission and detection of sound

- **nature of sound**

mechanical longitudinal wave – compression and rarefaction of (air) molecules

quiet sound



louder sound
(bigger difference in density)

- **source**

must vibrate, cause further compressions and rarefactions of the medium around

noise – irregular vibrations
musical notes – regular vibrations

- **transmitting media**

must contain particles – a vacuum cannot transmit sound!!! (pružné prostředí)

medium	speed of sound at 20°C in $m \cdot s^{-1}$
air	340
water	1500
glass, steel	about 5000

Discuss the values from the table. Explain why reinforced concrete is used to make sound barriers near motorways though sound travels much faster there than in the air.

- **detector**

must have some membrane able to vibrate – in microphones or ear drum ($\Delta p \approx 10^{-5}\,\text{Pa}$)

8. Sound properties

- **pitch**

depends on the lowest frequency of the vibrations of the source = the fundamental (1^{st} harmonics)
X the note higher by an octave has the fundamental twice as big (440 Hz – 880 Hz)

- **timbre (quality)**

depends on the multiples of the fundamental = overtones (2^{nd}, 3^{rd}, 4^{th} ... harmonics) –which of them the source produces and what their intensity is (the proportion of energy released in particular multiples of the fundamental).

NO TIMBRE – the source produces just one frequency = the fundamental – tuning fork, signal generator
TIMBRE of the sound is important for us to determine the instrument, person speaking/singing,...

- **intensity or loudness**

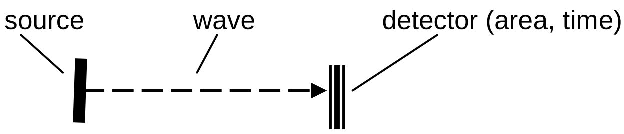
INTENSITY is the objective quantity measured by instruments/devices

= the rate of flow of energy through unit area perpendicular to the direction of travel of the sound
- can be applied for ultrasonic and infrasonic waves too

acting on the area of the detector

$$I = \frac{energy}{time \times area}$$

$$[I] = \frac{\mathrm{J}}{\mathrm{s \cdot m^{-2}}} = \mathrm{W \cdot m^{-2}}$$



$$I = \frac{P}{4\pi r^2}$$

P – power of the source
r – distance from the source

LOUDNESS is a subjective sensation defined for the human ear, it depends on each person!

$f \in (16\,\mathrm{Hz}, 16\,\mathrm{kHz})$ audible interval – some authors: 8 Hz, 20 kHz

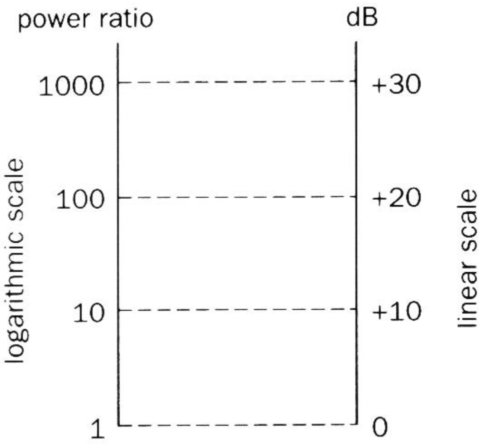
threshold of hearing – when the ear starts to detect the sound (depends on frequency)
threshold of pain

the DECIBEL – the unit of change in loudness used in medicine mainly

number of bells change = $\log_{10} \frac{P}{P_0}$

number of decibels change $B = 10 \log_{10} \frac{P}{P_0} = 10 \log_{10} \frac{I}{I_0}$

P, I – values of the sound for which we state the loudness
P_0, I_0 – threshold of hearing values



The decibel scale

Sound	dB level
Threshold of hearing	0
Whispering	30
Normal conversation	60
Busy street	70
Noisy factory	90
Jet plane overhead	100
Loud thunderclap	110
Threshold of pain	120

Doppler effect in sound
The frequency of the sound = the pitch can differ according to the relative motion of the source and detector.

http://www.walter-fendt.de/ph14e/dopplereff.htm

Task:
Give and discuss some examples of Doppler effect.

9. Infrasound and ultrasound

Infrasound has the frequencies lower than 16 Hz; ultrasound has the frequencies higher than 16 kHz. They are used by some animals to communicate, to state the distances in water (SONAR –sound navigation and ranging), ultrasound is used in medicine for prenatal diagnostics. Overdoses of infrasound and ultrasound are harmful, though we cannot hear them!

Task:
Compare the advantages and disadvantages of X-ray photographs and ultrasonic diagnostics.

Which animals use infra and which ultrasound for their communication?

10. Sound recording

Use different resources to explain how is sound recorded – “stored” - on a magnetic tape, conventional disc („record“) and compact disc (CD)

MAGNETIC TAPE

RECORD

CD

Answers:

1. b) -0.05 m
2. 0.1 m; 0.3 m; 1.5 $m \cdot s^{-1}$
3. b) -0.045 m
5. 4 cm; -2 cm; 0