

Physical bases of biophysics

Lecture 5 21. 09. 2021.

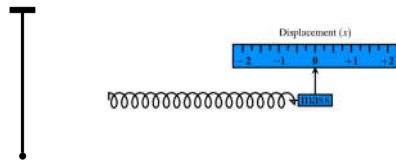
Ádám Orosz

1. Mechanics – Pressure, Hydrostatics



1. Fluid mechanics
2. Density
3. Hydrostatic pressure
4. Hydrostatic paradox and Pascal's principle
5. Archimedes' law and buoyancy
6. Pressure of gases
7. Partial pressure
8. Measuring blood pressure

2. Mechanics - Oscillations



1. Basic concepts of oscillations
2. Types of oscillations
3. Harmonic oscillations
4. Free oscillation and eigenfrequency
5. Mass-spring oscillator
6. Driven oscillation
7. Resonance

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Fluid mechanics

Fluid statics

Hydrostatics
(description of non-compressible fluids at rest)

Aerostatics
(atmosphere at rest)

Characterization of the internal state of gases and liquids

Pressure ↔ Density

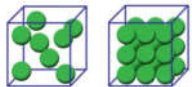
Fluid dynamics

Flow of fluids and gases

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Density

density (ρ):
$$\rho = \frac{m}{V} \left(\frac{\text{kg}}{\text{m}^3} \right)$$

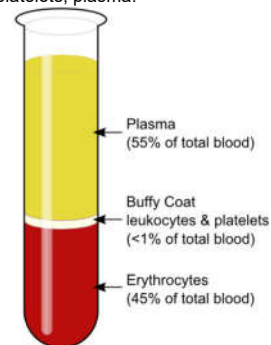


The density of an object is **influenced** by:

- **material**
- **pressure**
- **temperature**

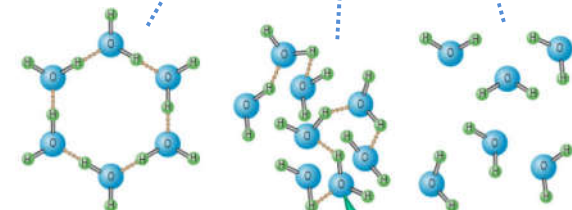
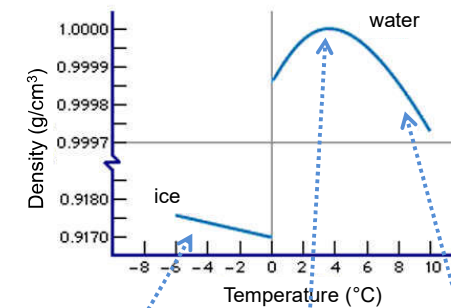
When anticoagulated blood is centrifuged, three distinct fractions are obtained due to the different densities of the components: red blood cells (erythrocytes); white blood cells (leukocytes) and platelets; plasma:

Material	ρ (g/cm ³)
air (0°C, 101 kPa)	0,00129
water (4°C)	1
adipose tissue	≈ 0,9
blood	≈ 1,05
bones	≈ 1,8
body tissue (average)	≈ 1,04
gold (Au)	19,3
mercury (Hg)	13,6



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Density of water



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Repetition - Pressure

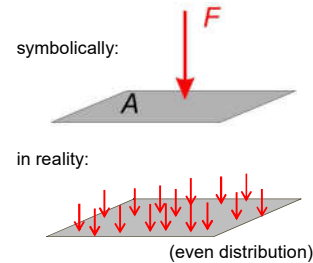


- The deformation of an object depends not only on the force acting on it, but also on the surface on which the force is applied.
- Power alone is not always enough to describe the interaction. We need a new quantity that also takes the surface into account. → „pressure“.

$$\text{pressure } (p): p = \frac{F}{A} \left(\frac{\text{N}}{\text{m}^2} = \text{Pa} \right)$$

Pascal

Other commonly used units:
bar (bar) = 100 kPa, atmosphere (atm) = 101, 325 kPa,
millimetre of mercury (mmHg) = 133,3 Pa



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Problem



How much pressure does an 80 kg man in a standing position exert on the ground if

a) if there is nothing on his feet? (the surface of the two soles is 200 cm²)

b) if the man skiing? (joint surface of the two skis is 3300 cm²)

c) if he is ice skating? (surface of the edge of the ice skates is 4 cm²)

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Hydrostatic pressure

originates from the weight of fluid



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Hydrostatic pressure

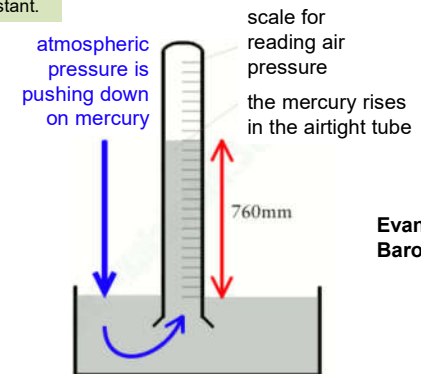
Pressure in gases and liquids due to gravity :

$$p = \rho \cdot g \cdot h$$

Comment:
The pressure thus increases linearly as a function of depth. However, this is only true in the case of an incompressible substance, when the density is constant.

Calculate the pressure exerted by the 1 mm high mercury column!

$$1 \text{ mmHg} = 133 \text{ Pa}$$



Evangelista Toricelli
Barometer (1643)

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Hydrostatic paradox



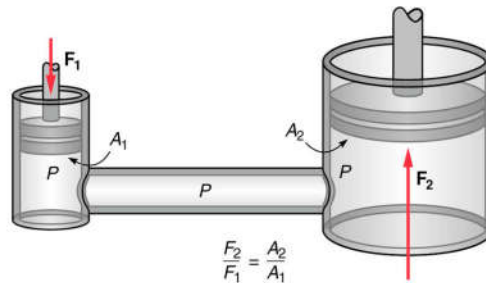
The **hydrostatic pressure** exerted by the liquid on the bottom of the vessel **depends only on the filling level** of the vessel, but **not on the shape** of the vessel and thus on the volume of liquid in it.



Blaise Pascal
(1623–1662)

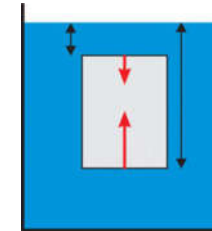
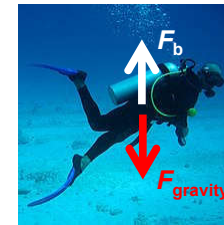
Pressure is transmitted undiminished in fluids because they are incompressible.
($\kappa_{\text{water}} = 0,5 \text{ GPa}^{-1}$)
(hydraulic jack, brakes)

Pascal's principle



Archimedes' law and buoyancy

Every body immersed in a liquid or gas is subjected to a buoyancy equal to the weight of the liquid or gas displaced by the body. Every body immersed in water loses as much weight as the weight of water it displaces.



A body that is submerged in a fluid is buoyed up by a force:

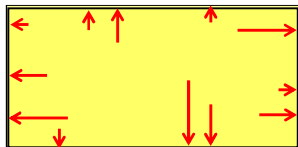
$$F_b = \rho_{\text{fluid}} g V$$

floating
($v = 0$)
 $a = 0$

$$\sum F = F_{\text{gravity}} - F_b = 0$$

$$F_{\text{gravity}} = F_b$$

Pressure of gases



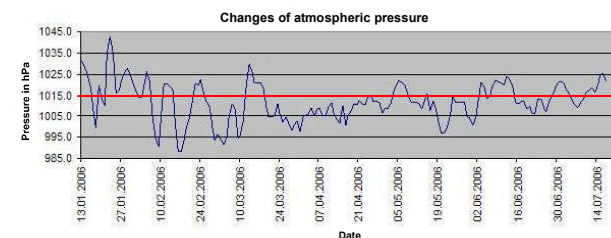
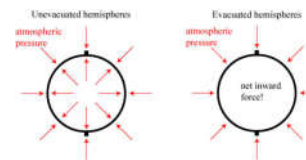
later:

$$pV = NkT$$

- Due to their **thermal energy**, the gas particles move in all directions (thermal energy is converted into **kinetic energy**).
- Gas particles collide with the tank wall**, and according to the ideal gas model this means a series of **elastic collisions**.
- When the particles collide with a wall, a **change in momentum** occurs, which according to Newton II. law results in **short surges of force**. The pressure of the gas will be the sum of the force shocks exerted on surface the wall.
- Considering the **large number of collisions** ($N \sim 6 \cdot 10^{23}$), the **quotient of the average force** and the **surface** of the tank gives the **pressure of the gas**.

Atmospheric pressure

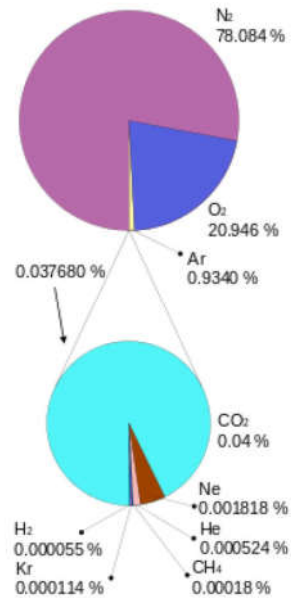
Experiment of Otto von Guericke
„The Magdeburg hemispheres“:



Normal atmospheric
pressure= 101 kPa = 1010
hPa

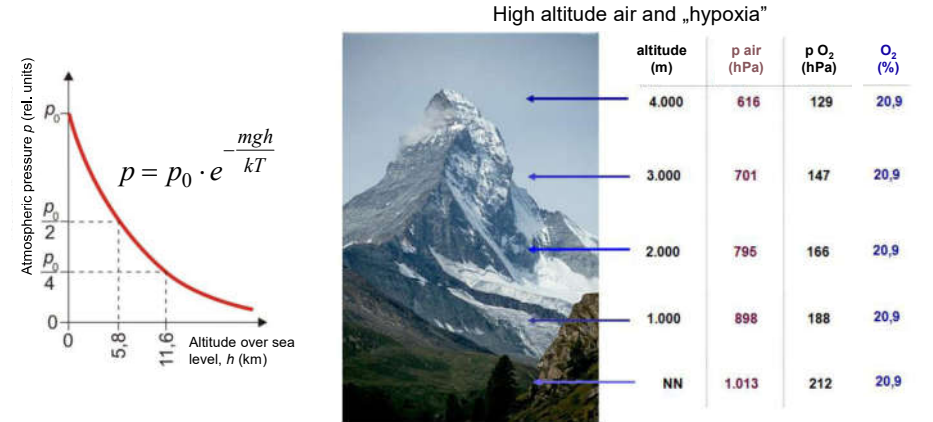
Partial pressure

- A concept for gas mixtures.
- Air is a mixture of gases (nitrogen, oxygen, carbon dioxide,...)
- Each component of the gas mixture contributes to the total gas pressure.
- The **partial pressure** corresponds to the pressure that one of the components of the gas mixture would exert if it filled the total volume available on its own.
- The sum of the partial pressures of the components gives the pressure of the gas.
- Example: the proportion of O₂ in the air is ~ 21%, so of the total pressure of 101 kPa, the partial pressure of O₂ is 21.2 kPa.



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Breathing at high altitudes

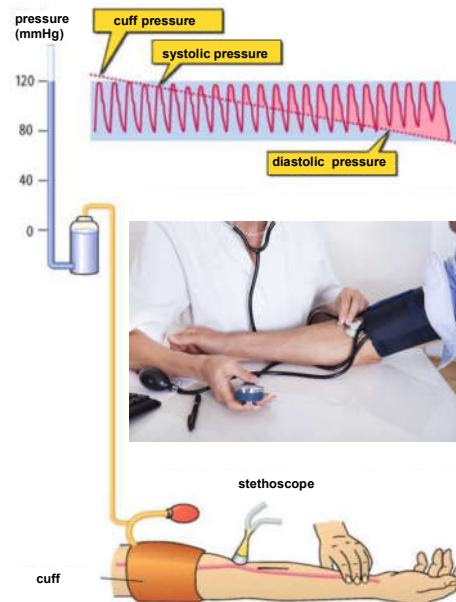


- The percentage composition of air does not change with altitude in the airspace relevant to humans.
- Nevertheless, it becomes difficult to breathe as the height increases, our performance decreases. (→ altitude training - to increase performance)
- The cause of this phenomenon is the **decreasing air pressure**, which also means a **decreasing partial pressure of oxygen**. This affects the body's uptake and release of oxygen.
- The body is able to adapt - the amount of hemoglobin and red blood cells increases.

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Blood pressure and its measurement

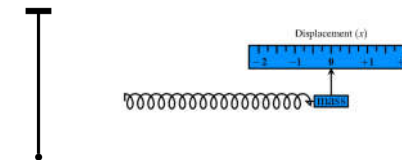
- We inflate the cuff until the pressure in the *Arteria brachialis* by approx. 20 mmHg.
- No blood flows into the arm (or out of it).
- Place the stethoscope over the *A. brachialis* and slowly begin to reduce cuff pressure.
- As soon as the cuff pressure drops just below the **systolic pressure**, the blood starts to flow again, then we hear sounds = **Korotkov sounds**
- As long as the cuff pressure is between the systolic and diastolic values, we can hear the sounds because the **blood flow** in this range will be **turbulent**.
- Once the diastolic value is reached, the sound effect - and the turbulent flow - ceases.



Comment:
The measured pressure value is overpressure (= pressure above normal atmospheric pressure).

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Mechanics – Oscillations

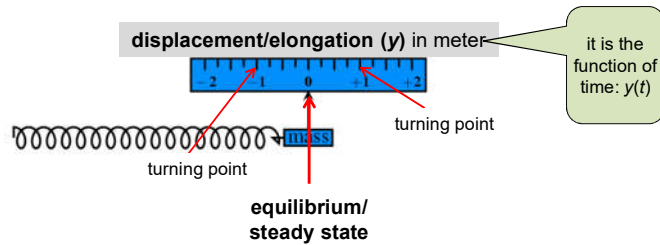


1. Basic concepts of oscillations
2. Types of oscillations
3. Harmonic oscillations
4. Free oscillation and eigenfrequency
5. Mass-spring oscillator
6. Driven oscillation
7. Resonance

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Basic concepts of oscillations

Oscillator: a physical system capable of oscillation (e.g. mass attached to a spring or pendulum).
Oscillation (mechanical): a periodic (repetitive) motion about a point of equilibrium.



Amplitude (A): maximal displacement

Reminder:

• **Period (T):** duration of one cycle in a repeating event; its base unit is the second (s).

• **Frequency (f):** number of cycles per unit time. The reciprocal of period:

$$f = \frac{1}{T} \quad \left(\frac{1}{s} = \text{Hz} \right)$$

• **Angular frequency (ω):** the number of cycles in 2π . 2π times the frequency: $\omega = 2\pi f$

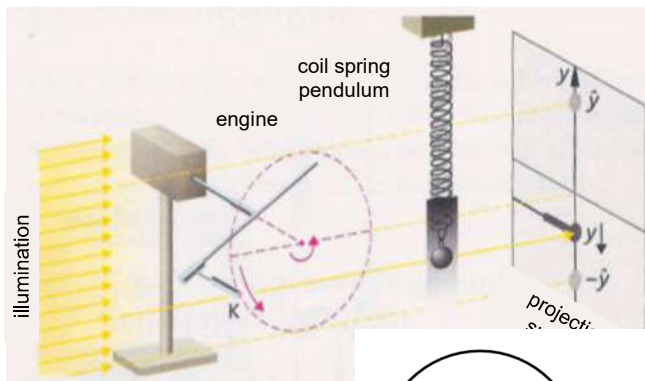
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Types of oscillations

Harmonic oscillation (sinusoidal oscillation)	Non-harmonic oscillation (non-sinusoidal oscillation)
pendulum clock, spring pendulum - spring oscillator	oscillations of the human vocal cord shock absorbers in cars
Free oscillation	Damped oscillation
speaker diaphragm during a sound at a given volume	Pendulum which is left to itself, vibration damper

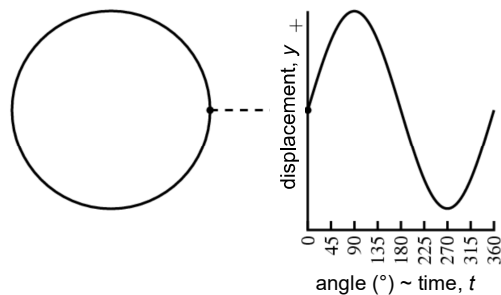
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Uniform circular motion– harmonic oscillation



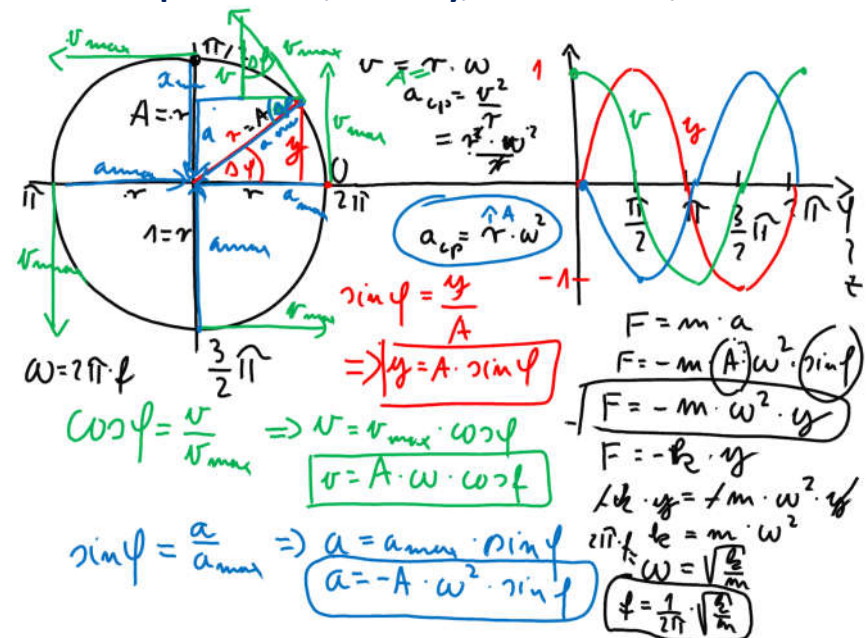
The general form of the displacement-time function:

$$y = A \cdot \sin(\omega t + \varphi_0)$$



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Displacement, velocity, acceleration, force



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Free oscillation

Prerequisite:

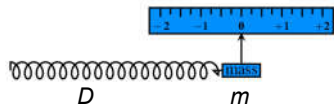
We displace the system and release it, creating an oscillation.

Free oscillation: oscillation that proceeds on its own without external influence.

Eigenfrequency (natural frequency): frequency of a free oscillation.

It is determined by the properties of the oscillator (mass, geometric quantities, material properties, etc.).

Mass-on-spring oscillator



$$f_{\text{natural}} = \frac{1}{2\pi} \sqrt{\frac{D}{m}}$$

Comment:

The equation is only valid in the ideal case, i.e. the oscillation is harmonic (not damped). In fact, there is always a loss of energy (friction, air resistance,...), so the oscillation is damped.

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Problem

Body weight is determined in space using a spring oscillator. The oscillator used for the measurement weighs 6.5 kg and has a period of 0.75 s. Together with the astronaut, the period increased to 2.7 s. Calculate the astronaut's mass!

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Driven oscillation

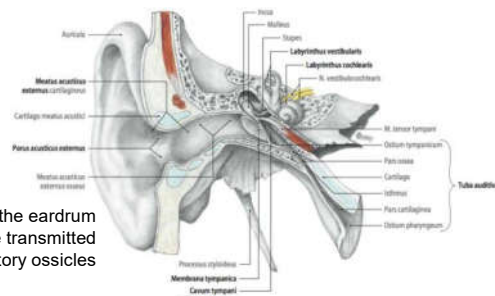
Oscillation caused by a periodic **external force**.



If one of the tuning forks is hit, the resulting air pressure fluctuations will also cause the other tuning fork to vibrate (provided that both forks are tuned to the same pitch).



Air pressure fluctuations vibrate the eardrum and then these vibrations are transmitted through the auditory ossicles

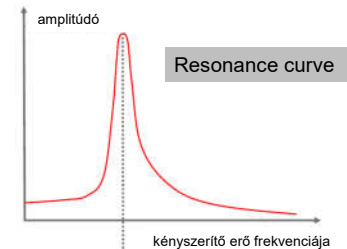


- During a driven oscillation, we can maintain the harmonic oscillation with a constant amplitude with the driving force, despite the energy losses.
- The oscillating system **takes up the frequency of the driving oscillation**.

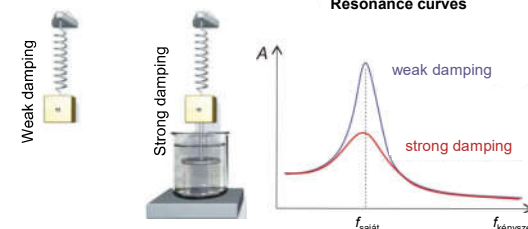
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Resonance

- If energy is periodically transmitted to an oscillating system by means of an **external driving system**, **driven oscillation** will develop after a certain settling time.
- Depending on the frequency of the driven oscillation, oscillations of different amplitudes are generated.
- If the **frequency of the driven oscillation coincides** with the **natural frequency of the system**, a particularly strong, high-amplitude driven oscillation is generated.
- A particularly high-amplitude oscillation at a given frequency is called a **resonance**, and a frequency characteristic of a phenomenon is called a **resonance frequency**.

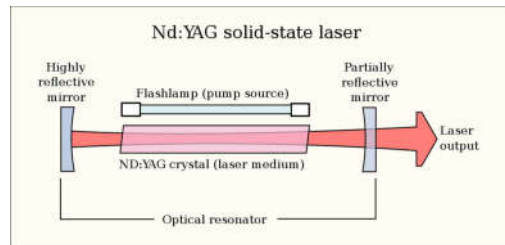
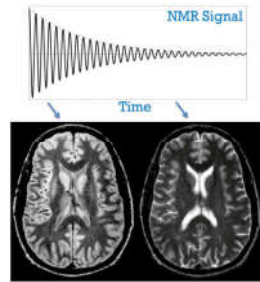


resonance frequency =
Natural frequency of the
oscillator



Comment:
The phenomenon of resonance is used in several technical devices (eg nuclear magnetic resonance spectroscopy and imaging, laser, ...)

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Homework: Chapter 6 and 7