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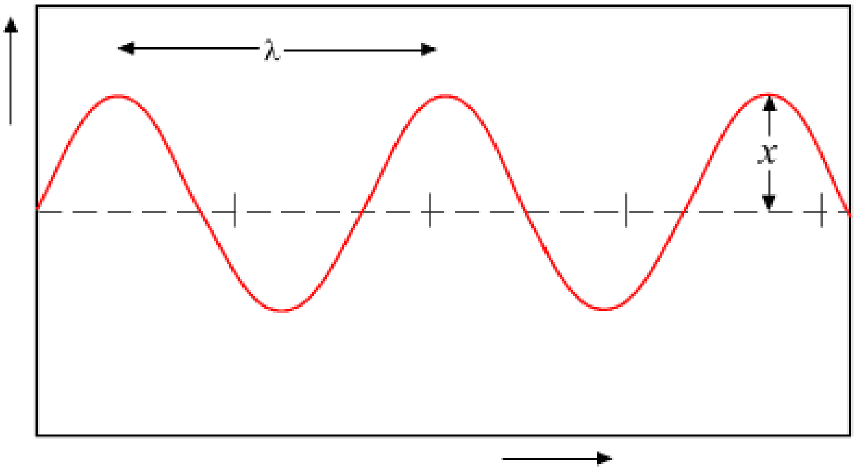
PHARMACEUTICAL PHYSICS



PART I:

Mechanics, Thermodynamics.
Molecular physics, Physics of liquids,
Phenomena of substance transport and heat transport,
Biophysics of the cell, nucleus and biological membranes,
synaptic transmission

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Pharmaceutical Physics – part I

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1. WHAT IS PHYSICS?

Physics (from Ancient Greek: physis φύσις "nature") is a field of science that developed from philosophy and was considered natural philosophy until the late 19th century, a term describing a field of study for "nature's way of working".

Today, **physics is traditionally defined as the study of matter, energy, and the relationship between them**. Physics is in one sense, the oldest and most elementary pure science; its discovery has applications in all the natural sciences, as matter and energy are the basic constituents of the natural world. Other sciences are generally more limited in their scope and can be thought of as branches that split off from physics to become sciences in their own right.

However, nowadays physics can be divided into classical physics and modern physics.

Physics has become more than the basic science that helps us understand the universe and the laws of nature. Physics has become the basis of an economy built on high-tech lasers, fiber optics, semiconductor devices, advanced materials, and many other innovations. This means that physics gives us the opportunity to build the future in the same way that it helps us understand the world around us. **The answer to fundamental questions in fields as diverse as medicine, materials science, general industry, business or politics lies in the principles and laws of physics.**

The fundamental objective of physics is to understand the transformation of matter and energy at all levels, from the origins of the universe during the Big Bang theory to the interior of the atom. **In their research and their attempts to understand and explain all this, physicists and physics have changed our lives.** Here are some of the achievements of the 20th century due to their scientific research: Electricity, radio, television and mobile telephony, travel to the moon or other planets, the transistor and the electronic revolution, including computer and computer networks. The first digital computer is the work of a physicist, Howard Aiken. The web (www) whose invention is due to the need of physicists to communicate quickly in a computer network, medical imaging, magnetic resonance imaging, ultrasound, positron emission tomography, endoscopy, the discovery of the Big Bang, black holes and the accelerated expansion of the Universe (http://phys.ubbcluj.ro/)

Physics is an art of understanding things. For thousands of years people have wondered why stars shine, why stone is hard or gold shines. Now we obtain the answers.

Da Vinci realized a preliminary drawing of a vortex in flowing water that we can now explain, he also sketched fantastic flying machines that we can now build.

People dreamed of being able to communicate between continents, touch the moon or look inside the atom. Now all these things have become reality.

Physics teaches us to transform an intractable problem into an intelligible one, solve it, and communicate the results clearly.

An experimenter is more than a scientist, he is an engineer, electrician, chemist, master mechanic, plumber (even more specialized in liquid helium than water), carpenter, expert programmer, inventor, writer and thinker.

2. MECHANICS

HISTORY OF MECHANICS

Knowledge of mechanics has existed since antiquity, especially problems of statics.

ARCHIMEDES (287-212 BC) designs the theory of the lever, the theory of the center of gravity (250 BC) lays the foundations of hydrostatics, makes many technical inventions.

The intensive development of mechanics begins in the Renaissance era:

LÉONARDO da VINCI (1452-1519) gives a theory of mechanisms, the study of the laws of friction, the theory of the inclined plane, defines and applies the moment of a force.

GALILEO GALILEI (1564-1642), the one who discovered the law of inertia, the law of falling bodies, the laws of the pendulum, etc.

CHRISTIAN HUYGENS (1629-1695) discovers the physical pendulum, the moment of inertia, introduces the concepts of centrifugal force, moment of inertia, center of oscillation and lays the foundations of the wave theory in his "Traité de la lumière".

ISAAC NEWTON (1643-1727) in his famous work "*PHILOSOPHIAE NATURALIS PRINCIPIA MATHEMATICA*" (1687) published the laws of dynamics and the construction of theoretical mechanics. He also formulates the law of universal gravitation and applies it to celestial mechanics.

Mechanics was developed by LEONARD EULER (1707-1783), JEAN D'ALEMBERT (1717-1783), JOSEP LAGRANGE (1730-1813), WILLIAM HAMILTON (1805-1865), etc.

The stability of dynamic systems was studied by H. POINCARE (1854-1912) and M.A. LIAPUNOV.

The dynamics of bodies with variable mass was developed by I .V. MESCERSKI (1859-1935) and T. LEVI-CIVITA (1873-1941).

In Romania, ANGHEL SALIGNY, SPIRU HARET, ANDREI IOACHIMESCU, ION IONESCU, GH. EM. FILIPESCU, V. VALCOV, O. ONICESCU offered valuable contributions.

LIMITATIONS OF MECHANICS

Neo-Newtonian concepts have long had a strong influence on all of physics.

Thus was born a **mechanistic conception of nature, according to which all natural sciences had to be reduced to mechanical laws** .

This point of view was rejected at the end of the last century, given the impossibility of reducing electromagnetic phenomena to mechanical movements.

An electromagnetic picture of the world was created which explains all phenomena through electromagnetism. **Also, this explanation is not possible because nuclear forces cannot be reduced to electromagnetic forces,** thus matter being infinite and inexhaustible, no theory can be universal and definitive. The application of classical Newtonian mechanics is limited only to organisms of ordinary or large size (macroscopic) and to small velocities compared to the speed of light in a vacuum ($c = 3 \cdot 10^8$ m/s).

For high speeds close to the speed of light, relativistic mechanics was created in 1905 by ALBERT EINSTEIN (1879-1955).

For atomic-sized particles, the quantum mechanics of SCHRÖDINGER W. HEISENBERG, L. DE BROGLIE, PAM DIRAC and others was created in 1925 .

SIMON STEVIN (1548-1620) created the balance on the inclined plane and noted the decomposition of forces into components (parallelogram rule).

The foundation of dynamics (motion itself) is due to **GALILEO GALILEI** (1564-1642) **and its development by CHRISTIAN HUYGENS.**

ISAAC NEWTON (1643-1727) **transformed it to a degree of perfection, which is why it is called NEWTONIAN DYNAMICS in his honor.**

GALILEO GALILEI's experiments on falling bodies began soon after 1589, and Newton's book " *PHILOSOPHIAE NATURALIS PRINCIPIA MATHEMATICA* " appeared in 1687.

So, **the dynamic has been created for almost a century**, the result of this achievement is contained in two principles:

the product of the mass and the acceleration of a point is equal to the force exerted on it (acceleration and force are oriented vector quantities and the principle requires, among other things, that both have the same direction). This is **the fundamental principle of dynamics.**

To this is added **the principle of action and reaction: the forces exerted between two masses are of equal and opposite magnitude.**

The meaning of acceleration became clear from the time of Galileo who studied with primitive means the concept of variable speed. Newton created together with GOTTFRIED WILHELM LEIBNIZ (1646-1716) the infinitesimal calculus, which could facilitate this work.

Acceleration is the change in velocity with respect to unit time, the derivative of velocity with respect to time, and therefore the second derivative with respect to time of the radius vector. If we are clear about the measurement of position and time, the explanation of the concepts of velocity and acceleration follows naturally.

The first principle gives a 2nd order differential equation for the position of the point as a function of time, integration of the equation gives the trajectory and the speed with which it is traveled.

If no force appears, $F = 0$ and motion occurs at a constant speed according to the principle of inertia. Newton's theory of gravity was superseded by Einstein's theory of general relativity in 1916.

The above theories are qualitatively different from mechanics, but contain it as a special or limiting case (correspondence principle).

The theory of balance - STATICS - has its roots in distant antiquity: lever, screw, pulley, inclined plane that facilitated human existence. Notions such as specific gravity, center of gravity were developed by the Greeks. Statics culminated in the principle of virtual displacements: it is necessary to calculate for each material point the product of the force with the distance that its point of application would travel if a movement in the direction of the force would occur.

The law of leverage is a special case, and Archimedes' principle is another special case. ROBERT KIRCHHOFF (1824-1887) in his "Lectures on Mechanics", stated that LOUIS POISON (1777-1859) gave definitive form to rigid body mechanics. .

GASPARD-GUSTAVE CORIOLIS (1792-1843) examined the influence of the Earth's rotation on the processes taking place there.

LOUIS AUGUSTIN CAUCHY (1789-1859) gave in 1822 the most general mathematical formulation of the notions of elastic tension and deformation. Cauchy and Hooke gave the definitive form to the mechanics of deformable bodies.

WILLIAM ROWAN HAMILTON (1804-1865) stated the principle of least action.

GUSTAV CARL JACOBI (1804-1851) created the Hamilton-Jacobi differential equation method for many-body systems.

LORD RAYLEIGH (1842-1919), OSBORNE REYNOLDS (1842-1912), LUDWIG PRANDTL (1875-1953) developed the dynamics of liquids and gases taking friction into account, especially for the needs of hydro and aeronautical construction.

What matters is the difference between an orderly "laminar" flow and "turbulent" flow.

The most important is Hamilton's principle of least action, which HELMHOLTZ HERMAN (1829-1894) extended in 1866 as the main topic of a whole series of mechanical processes.

MAX PLANCK (1858-1947) saw in this principle the most complete of the laws of nature.

W.R. HAMILTON revealed that the trajectories of all material points emerging at the same speed from the same point create a mechanically "optical" image.

Mechanics is the science of motion; its purpose is to describe completely and in the simplest way the movements that occur in nature.

In the interval between Galileo's time and that of Newton, other axes of development took place.

TORRICELI EVANGELISTA (1608-1647) invented the mercury barometer in 1644.

OTTO VON GUERICKE (1602-1686) built the pneumatic machine and explained by many impressive experiments the nature of air pressure.

For the mechanics of solids, a contemporary of PASCAL, **ROBERT HOOKE (1635-1703) discovered in 1676 on the basis of simple examples the proportionality of deformation and force.**

BERNOULLI DANIEL (1700-1782) and LEONNARD EULER (1707-1783) studied systems of new material points and dealt with rigid body and hydrodynamics.

JEAN LE ROND D'ALEMBERT is the author of the principles that replace the equations of motion (named after him).

PIERRE SIMON DE LAPLACE (1749-1827) wrote "Celestial Mechanics" in five volumes around 1800 which includes more than its title promises, including a theory of waves in liquids and capillarity.

QUANTITIES AND PHYSICAL UNITS

TRANSFORMATION OF UNITS

PHYSICAL QUANTITIES AND MEASUREMENTS

Physical Phenomenon (process or transformation) is a sequence of changes in a body or a system of bodies that evolves over time, following a certain law.

All these changes are subject to the study of physics and are evaluated through qualitative and quantitative observations.

MEASUREMENT is a process by which the physical quantity in question is compared with a defined quantity of the same nature that has been chosen as a unit of measurement. This comparison (or measurement) is done using a measuring instrument.

Examples of units:

length: 1 meter (m)
time: 1 second (s)
mass: 1 kilogram (kg)

Some physical quantities are fundamental quantities, which are defined only by describing the measurement process.

For example, distance is measured by using a ruler, and time is measured with a chronometer/stopwatch. Other physical quantities are derived quantities, which are defined by different formulas using fundamental quantities.

For example, **speed is the ratio of the distance traveled by a body in a specific time interval.**

Different systems of units have been used over time – sets of fundamental physical quantities and their corresponding units of measurement.

INTERNATIONAL SYSTEM OF MEASUREMENT (SI) considered the most commonly used system, operate with the following fundamental/base quantities and units:

No	Physical quantities	Unit	SI	CGS
1	Time	Second(s)	s	s
2	Distance	Meter (m)	m	cm
3	Mass	Kilogram (kg)	kg	g
4	Temperature	Kelvin	K	K
5	Amount of substance	Mole	Mole	Mole
6	The intensity of the electric current	Ampere	A	A
7	Light intensity	Candle	Cd	Cd

DEFINITION OF FUNDAMENTAL UNITS OF MEASUREMENT

METER - length unit (m) being the length equal to 1650763.73 vacuum wavelengths of the radiation corresponding to the transition between the 2p 10 and 5d 5 energy levels of the krypton 86 atom.

λ= 605.78 nm (yellow)

Note: The definition of meters was adopted by the 11th General Conference on Weights and Measures in 1960 by its sixth resolution .

From 2019, the definition of the meter is as follows: the meter is the length of the path traveled by light in a vacuum in 1/299 792 458 of a second.

KILOGRAM - the unit of mass (kg) is the mass of the international prototype of the kilogram. The term denotes the same quantity as a force $G = m \cdot g$, where g is the gravitational acceleration; $g = 9.80665\ m/s^2$

Note: The definition of the kilogram was adopted by the First and Third General Conferences of Weights and Measures in 1889 and 1901 respectively. The kilogram as the "international prototype" is kept at the International Bureau of Weights and Measures in Sèvres, under the conditions defined by the Conference General for Weights and Measures of 1889.

__From 2019:__ ***The kilogram is defined by fixing the value of Planck's constant h to the exact value of 6.62607015×10−34 J·s***
(J = $kg{\cdot}m^2{\cdot}s^{-2}$), given the definitions of meter and second.The formula thus becomes kg = h/(6.62607015×10−34·m2·s−1).

SECOND - the time unit (s) is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium atom Cs^{33}.
Note: The second definition of the second was adopted by the 13th Conference of Weights and Measures in 1967 in the first resolution.

AMPERE – the unit of measure for the intensity of electric current (A). Amperes is the electric current that is maintained in two parallel, straight conductors, of infinite length and circular section, negligible placed under vacuum at 1 m distance from each other, that will produce a force of 1 N between these conductors over a length of 1 m.
Note: The definition of the Ampere was adopted by the Conference of Weights and Measures in 1948 by resolution 2.
__From 2019:__ ***The ampere is defined as a current of 1/(1.602176634×10−19) elementary charges per second.***

CANDELA – unit for luminous intensity (Cd)
The candela is the luminous intensity in a given direction of a source emitting monochromatic radiation with a frequency of 540.10^{12} Hz and has the radiant intensity in this direction.
Note: The definition of candela was adopted by the 16th Conference on Weights and Measures in 1979.

KELVIN - thermodynamic temperature measurement unit (K)
A kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
Note: The Kelvin definition was adopted by the 13th Conference on Weights and Measures in 1967 in its Fourth Resolution.
The same unit of measurement and the same symbol are used to evaluate a temperature range.
__From 2019:__ ***The Kelvin is defined by fixing the numerical value of Boltzmann's constant k to*** $1.380649\times10^{-23}\ J{\cdot}K^{-1}$, ***(J =*** $kg{\cdot}m^2{\cdot}s^{-2}$***), given the definitions of the kilogram, meter, and second.***

MOLE – unit for the amount of substance (mol):

The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kg of C^{12}.

When using moles, the elementary entities must be specified, they can be atoms, molecules, ions, electrons, other particles, or specified groupes of such particles.

Note: The definition of mole was adopted by the 14th Conference on Weights and Measures in 1971

From 2019*:* ***The amount of substance (mole) equals to exactly 6.02214076×10^{23} elementary entities. This is the fixed numerical value for Avogadro's constant N_A when expressed in the unit mol^{-1} and is called Avogadro's number.***

HISTORY AND DEVELOPMENTS

THE FIRST ATTEMPT FOR AN UNIVERSAL SYSTEM OF UNITS

The first notable attempt to establish universal units (i.e. based on reproducible physical phenomena) is undoubtedly that of **John Wilkins**, an English scientist member of the Royal Society, **who in 1668 defined a length, then an universal volume, and, finally, a universal mass (that of the amount of rainwater contained in a cube of side equal to the universal length).**

The universal length thus defined is taken to be equal to 38 Prussian inches (about 993.7 mm.), **or about that of a simple pendulum whose half-period of small oscillations is one second**[1] .

Around 1670, Gabriel Mouton, a religious from Lyon, proposed a unit of length based on the measurement of an arc of the terrestrial meridian. It also defines the series of multiples and submultiples of units based on the decimal system[2].

In 1675, the Italian scientist Tito Livio Burattini renamed the universal measure of **the John Wilkins meter** and took as the exact definition that of the previously described pendulum (and no more than 38 Prussian inches), thus reaching a length of 993.9 mm[3]. However, this value depends on the acceleration of gravity and therefore varies slightly from place to place.

THE FRENCH REVOLUTION AND THE BIRTH OF THE METRIC SYSTEM

In 1790, the National Constituent Assembly decided, on the proposal of Talleyrand, himself advised by Condorcet, to create a stable, uniform and simple measurement system, and Burattini's unit was first adopted as the base unit.

But since the length of the pendulum that beats per second is not the same depending on where you are, due to the difference in gravity depending on the distance from the equator (see above), it is ultimately ten millionths from a *quarter* of a meridian that was tentatively chosen in 1793. Two scientists were responsible for making the necessary geodetic measurements, Delambre and Méchain, who for seven years measured the distance between Dunkirk and Barcelona[1].

With the meter, the units of volume and mass are defined: **thus creating the metric decimal system**, facilitating the conversion of units because, from now on, to go from a unit to its multiples (and sub-multiples) is sufficient to move the comma. In the same year, the National Convention provides for the creation of standards for the meter and grave (the original name of the kilogram). The definition chosen in this way was definitively adopted on the 18 Germinal, Year III (April 7, 1795) by decree of the French National Convention. This metric system is then designated by the acronym MKpS, for meter, kilogram-weight, second.

The standards of the meter, in platinum, prescribed by the decrees of the National Convention are deposited in the National Archives of France on 4 Messidor, Year VII (June 22, 1799), which is **sometimes considered the founding act of the metric system.**

Introduced by the law of 13 Vendémiaire, Year IV (September 23, 1795), the metric system was made mandatory in France on the occasion of its fifth anniversary by the decree of 13 Brumaire, Year IX (November 4, 1800), the use of any other system is prohibited. In his memoirs about Saint Helena, Napoleon, who once supported the geodetic expedition to determine the new measure but realized the difficulty of acclimatization to new units, wrote:

“The need for uniformity of weights and measures has been felt throughout the centuries; several times the states-general emphasized this [...] The law in this matter was so simple that it could be drafted in twenty-four hours [...] It was necessary to make common in all the provinces the unit of weights and measures the city of Paris […] The inspectors, the algebraists, were consulted on a problem that was only within the competence of the administration. They believed that the unit of weights and measures must be deduced from a natural order, so that it would be adopted by all nations […] From that moment a new unit of weights and measures was decreed which did not fit the regulations in public administration, nor with the tables of dimensions of all the arts […] There was no advantage in this system extending to the whole universe; that, moreover, was impossible: the national spirit of Englishmen and Germans would have opposed [...] Yet the good of the present generations was sacrificed to abstractions and vain hopes [...] utterly foreign to use. of the unit of weights and measures; they adapted decimal numbering […] they suppressed all complex numbers. Nothing is more contrary to the organization of the mind, memory, and imagination […] Finally, they used Greek roots, which increased the difficulties; these confessions, which could be useful to scholars, were not good for the people […] The people are struggling for trifles!!! »

EVOLUTIONS OF THE METRIC SYSTEM IN THE 19TH CENTURY

In 1832 Gauss worked to apply **the metric system as a coherent system of units in the physical sciences**. It establishes absolute measurements of the Earth's magnetic field using **a system of units based on the centimeter, gram, and second units, sometimes called the "Gaussian system"[1].**

In the 1860s, Maxwell and Thomson became involved with the British Association for the Advancement of Science (BA), founded in 1831, to establish a system of units consisting of base units and derived units. This led **in 1874 to the creation of the "CGS system" based on the units of centimeter, gram and second.**

In the 1880s, the BA and the International Electricity Congress, the forerunner of the International Electrotechnical Commission **agreed on a system of practical units, including the ohm, volt and ampere**.

THE FRENCH REVOLUTION AND THE BIRTH OF THE METRIC SYSTEM

This is why, on February 12, 1812, Napoleon issued an imperial decree establishing new units for trade with a name compatible with ancient usage, such as *ell, toise, bushel, pound* , but with new values fixed with reference to the metric system and, above all, allowed non-decimal fractions for these new units.

After the French Restoration of 1814, Louis XVIII initially confirmed that he wished to pursue the establishment of the metric system, but under pressure from complaints, a ministerial decree of 21 February 1816 ordered the suppression of decimal fractions of weights and measures and the exclusive use of "ordinary" measures for the retail sale of food products and goods. The metric system was not abandoned in education, however, and little by little people realized that it was time to abandon the facilities introduced by the decree of 1812 and to respect the legal units established by the decree of 13 Brumaire, year IX. It will be subject to the law of July 4, 1837 signed by Louis-Philippe which makes the use of metric system units mandatory in commerce and in civil and legal life.

As early as 1801, the Helvetic Republic wanted to introduce the metric system, but the law was never enforced (until 1877). The United Kingdom of the Netherlands (which then united the future Benelux countries) was the first to readopt it in 1816 at the instigation of its sovereign William I of the Netherlands, fourteen years before the French Revolution in 1830, marking its reintroduction to France.

In France, the law of July 4, 1837, made the use of the metric system mandatory from January 1, 1840 .

In **1832, Gauss** worked to apply the metric system as **a coherent system of units** in the physical sciences. Establish absolute measurements of the Earth's magnetic field using **a system of units based on the units: centimeter, gram and second sometimes called the "Gauss system"** .

In the 1860s, Maxwell and Thomson became involved with the British Association for the Advancement of Science (BA), founded in 1831, to establish a system of units consisting of base units and derived units. This led in 1874 to the creation of the "CGS system" based on the units of centimeter, gram and second.

In the 1880s, the BA and the International Electricity Congress, the forerunner of the International Electrotechnical Commission, agreed on a system of practical units, including ohms, volts and amperes.

WORLDWIDE USE

Most countries in the world have made the international system their official system of units. In East Asia it was at the beginning of the 20th century. This action (the official switch from a national system of units to the metric system) is called metrication.

In addition, it is legal to use the international system of units in all countries of the world.

As of 2008, ***only three countries in the world have not officially adopted the international system*** **: the United States, Liberia and Burma**.

However, **in the United States,** use of the metric system is becoming more widespread among scientists, medicine, government, and several sectors of industry.

In the United Kingdom, the use of the metric system has been compulsory since 1897; but in certain fields - commerce, public health, security, administration, road signs and the sale of precious metals, the equivalent in imperial units is *tolerated.* Fields (aviation, navigation, etc.) where non-metric units are used in other countries should also be added to this list. However, it is important to differentiate between legal obligation and tolerance - in the same way as in France, we distinguish between customary law, usage and legal texts.

Most *non-metric units of measurement* are now defined using SI units. For example, the National Institute of Standards and Technology publishes a table of definitions of **US units of measurement** based on metric units.

OTHER UNITS

Plane angle - measured in radians.

The radian is the plane angle having its apex at the center of a circle and delimiting on the circumference of the circle an arc whose length is equal to the radius of the circle.

The definition of radian was adopted by the International Organization for Standardization (ISO) in Recommendation R31, Part 1.

Solid angle - measured in steradians.

The steradian is the solid angle having the apex of a sphere and which delimits on the surface of the sphere an area equal to the area of a square whose side is equal to the radius of the sphere.

The definition of steradian was adopted by the International Organization for Standardization (ISO) in Recommendation R31, Part 1.

Standard length

The first standard length was a bar of platinum-iridium alloy called the standard meter in 1959 and it is defined as: 1 yard=0.9144m, 1 inch=2.54cm.

CGS system

CGS system is a system of units of measurement of physical quantities, where the basic units are:

length: 1 centimeter (cm)
time: 1 second (s)
mass: 1 gram (g)

BASIS AND USE

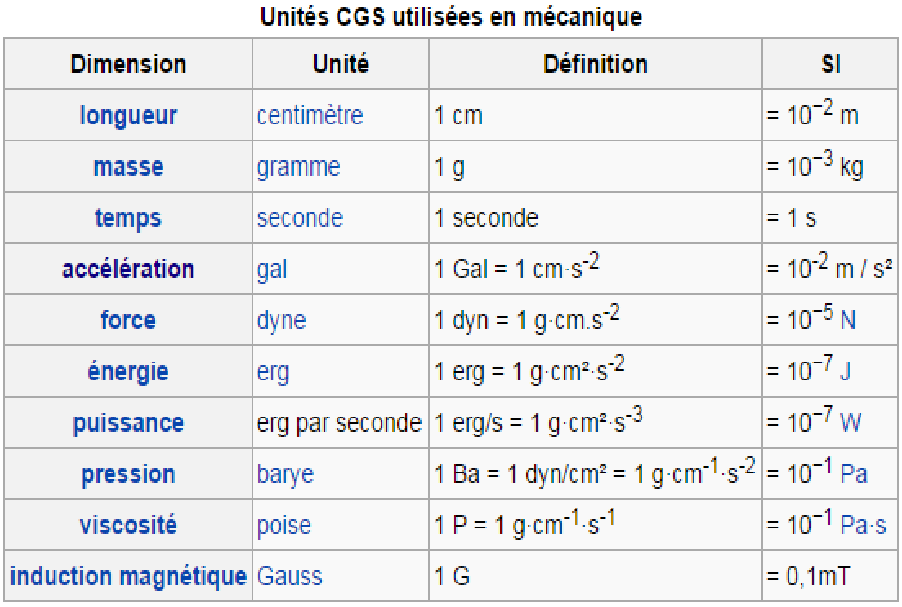
***CGS* system** was proposed by the British Association for the Advancement of Science in 1874. It was used in science until the middle of the 20th century.

In 1946, the International Committee of Weights and Measures **approved the MKSA (metre , kilogram , second , ampere) system.**

Currently, the international system of units retains seven base units.

***CGS* system** remains widely used in chemistry (especially in the laboratory) because it is more conceivable to have quantities of reagents on the order of grams and cubic centimeters than on the order of kilograms and cubic meters.

***CGS* system** is also widely used in astronomy, where fluxes are often expressed in erg/s/cm^2 /Hz or even gravimetry .



Unités CGS utilisées en mécanique

Dimension	Unité	Définition	SI
longueur	centimètre	1 cm	= 10^{-2} m
masse	gramme	1 g	= 10^{-3} kg
temps	seconde	1 seconde	= 1 s
accélération	gal	1 Gal = 1 cm·s^{-2}	= 10^{-2} m / s²
force	dyne	1 dyn = 1 g·cm.s^{-2}	= 10^{-5} N
énergie	erg	1 erg = 1 g·cm²·s^{-2}	= 10^{-7} J
puissance	erg par seconde	1 erg/s = 1 g·cm²·s^{-3}	= 10^{-7} W
pression	barye	1 Ba = 1 dyn/cm² = 1 g·cm^{-1}·s^{-2}	= 10^{-1} Pa
viscosité	poise	1 P = 1 g·cm^{-1}·s^{-1}	= 10^{-1} Pa·s
induction magnétique	Gauss	1 G	= 0,1mT

Time intervals	**s (second)**
the age of the earth	**$1.2 \cdot 10^{17}$**
the average age of a man	**$2 \cdot 10^{9}$**
Duration of Earth's revolution around the Sun (1 year)	**$3.1 \cdot 10^{7}$**
Duration of Earth's rotation around its axis (one day)	**$8.6 \cdot 10^{4}$**
The half-life of free neutrons	**$7 \cdot 10^{2}$**
Time between two normal heartbeats	**$8 \cdot 10^{-1}$**
The period of the tuning fork that gives the note A	**$2.3 \cdot 10^{-3}$**
The typical period of rotation of a typical molecule	**$1 \cdot 10^{-12}$**
The half-life of neutral pawns	**$2.2 \cdot 10^{-16}$**

Distance	**Unit m (meters)**
Distance to the most distant quasar	$6 \cdot 10^{25}$
Distance to nearest nebula (The Andromeda Sea Nebula)	$2 \cdot 10^{22}$
the radius of our galaxy	$6 \cdot 10^{19}$
Distance to the nearest star (Alpha Centauri)	$4.3 \cdot 10^{16}$
Sunshine	$6.9 \cdot 10^{8}$
Earth radius	$6.4 \cdot 10^{6}$
The size of a man	$1.8 \cdot 10^{0}$
The thickness of a book	$4 \cdot 10^{-2}$
The thickness of a book page	$1 \cdot 10^{-4}$
The size of a polio virus	$1.2 \cdot 10^{-8}$
The radius of a hydrogen atom,	$5 \cdot 10^{-11}$
The effective radius of a proton	$1.2 \cdot 10^{-15}$

TRANSFORMATION OF THE UNIT OF MEASUREMENT

For Force: $[F]_{SI} = 1N = 1\ (kg.m)/s^2$

For Force: $[F]_{CGS} = 1dyn = 1\ (g.cm)/s^2 = 1.(10^{-3}\ kg.10^{-2}\ m)/s^2 = 10^{-5}\ N$

For energy: $[E]_{SI} = 1J = 1\ Nm = 1\ (kg.m^2)/s^2$

For energy: $[E]_{CGS} = 1erg = 1(g.cm^2)/s^{2=}\ 1.(10^{-3}\ kg.10^{-4}\ m)/s^2 = 10^{-7}\ J$

OTHER UNITS

Force units :

1 dyn = 10^{-5} N

1kgf = 9.81N

Mass units :

1 pound (lb) = 453.5923 g = 0.4535923 kg

1 ounce (oz) = 28.35 g

Energy units

1 erg = 10^{-7} J

1kcal= $4,186.10^{3}$ J

1 eV = $1.602.10^{-19}$ J

1kWh=$3,6,10^{6}$ J

Distance units

1 in (inch) = 25.4 mm

1 yd (yard) = 0.9144 m

1 mile = 1609.344 m

1 nautical mile = 1853.18 m

Area units

1 ar=100 m^2

1ha= 10000 m^2

1 acre = 4046.86 m^2

1 in^2 = 645.2 mm^2

1 $yd^{2\ =}$ 0.9144 m^2

Volume units

1 US gallon = 3.785 L = 3785 m^3

1 UK gallon = 4.546 L =4546 m^3

1 barrel of United States oil = 158.98 l

1 oz (liquid) = 28.413 cm^3 = 1.7339 in^3

Temperature units

Temperature in degrees Fahrenheit:

TF = (9/5) · t^0C + 32

T = 5/9 (TF-32)+ 273.15

- where TF is the temperature in degrees Fahrenheit

Temperature in Réaumur degrees: t = TK - 218.52

Other units

1 g (SI) = 0.03527 ounces

1 feddan (Egypt) = 1.038 acres = 0.42 hectares

1 ardeb (Egypt) = 191,612 l

1 hamlah (Egypt) = 74,890 kg

1 drachma (Turkey) = 3.207g

1 cupisco (Sicily) = 22.1981 l

1 cuartilo (Mexico) = 0.547 l

1 QUARTERON (Spain) of oil = 0.151 l

1 dinero (Spanish) = 1,199 g

1 chittak (India) = 58,319 g

1 Bunce (Indonesia) = 46.344 g

1 bercocvici (Russia) = 163.85 kg

1 pud (Russia) = 16.381 kg

1 barrel of cement (USA) = 170,550 kg

barrel of oil (USA) = 158.987 kg

1 iron (unit of skin thickness) = 1/48 in = 0.539 mm

1 koku (Japan) = 180.4857 dm^3

1 Kivan (Japan) = 3.75 kg

FOR THE STRENGTH

1 dyn = 10^{-5} N or 1 kgf = 9.81 N

FOR MECHANICAL WORK

1 erg = 10^{-7} J

1P (equilibrium) = 1 dyn·s/cm^2 = 0.1 Pa·s

1 st = (places) = 1 cm^2/s = 10^{-4} m^2/s

1 gauss = 1 Gs = 10^{-4} T

1 Oersted = 1 Oe = $(100/4\ \pi) \cdot (A/m)$

1 inch = 25.4 mm

1 yard = 0.914 m

Units derived from the International System of Units

No	Derived quantity	Unit	Definition of the unit of measurement
1	surface	1 m^2	a square area with side of 1 m
2	volume	1 m^3	the volume of a cube whose sides are 1 m
3	velocity	1 m/s	a distance of 1 m traveled in 1 s
4	angular velocity	1 Rad/s	angle of 1 Rad in 1 s
5	acceleration	1 m/s^2	velocity variation of 1 m/s in 1 s
6	angular acceleration	Rad/s^2	change in angular velocity by 1 rad/s in 1 s
7	frequency	Hz or s^{-1}	
8	density	1 kg/m^3	the mass of a body of 1 kg with a volume of 1 m^3
10	power	N	1 Newton is the force which, being applied to a mass of 1 kg, creates an acceleration of 1 m/s^2
11	pressure	Pa or N/m^2	1 Pascal is the pressure that acting uniformly on a flat surface with an area of 1 m^2 exerts a total force of 1N which is orientated perpendicular to the surface
12	dynamic viscosity	Pa·s or kg/m·s	Pascal multiplied by the second is the dynamic viscosity of a homogeneous fluid in which a uniform rectilinear motion of a plane surface with an area of 1 m^2 gives rise to a frictional force of 1 N, thus the difference in velocity between two parallel layers located at a distance of 1m from each other, is 1 meter per second.
13	mechanical work	1J=1N·m	The work done by a force of 1 N acting in the same direction over a distance of 1 m
14	power	W or Kg · m^2/s^2	The power corresponding to the energy transfer of 1 J occurring in 1 second

Prefixes of multiples and submultiples of measurement units			
10^{-1}	deci	10^{1}	deca
10^{-2}	centi	10^{2}	hecto
10^{-3}	mili	10^{3}	kilo
10^{-6}	micro	10^{6}	mega
10^{-9}	nano	10^{9}	giga
10^{-10} m	Å (Angstrom)	10^{10}	
10^{-12}	pico	10^{12}	tera
10^{-15}	femto	10^{15}	peta
10^{-18}	atto	10^{18}	exa
10^{-24}	yocto	10^{21}	zetta
10^{-27}	ronto	10^{24}	yotta
10^{-30}	quecto	10^{27}	ronna
		10^{30}	quetta

SCALAR AND VECTOR QUANTITIES
OPERATIONS WITH VECTORS

PHYSICAL QUANTITIES ARE DIVIDED IN TWO TYPES:

- **scalar quantities**
- **vector quantities**

Scalar physical quantities may have positive or negative values.

Examples: time, mass, volume, density, pressure, energy, power.

Physical vector quantities are characterized by:

magnitude, direction and sense

Examples: velocity, acceleration, force

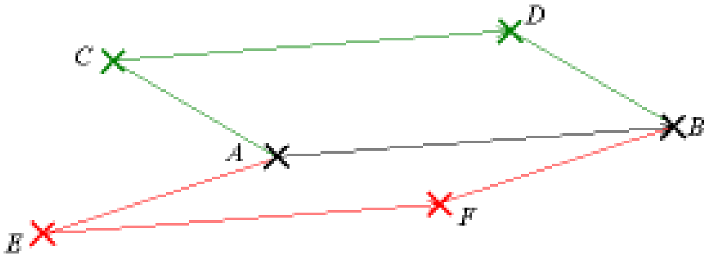
Vectors are denoted by the arrow above the normal letters: $\vec{v}$

The vector is represented by an arrow.

The direction is determined by the line – support.

The sense of direction is defined by the arrow head

Steering can be left or right on the steering wheel.



Be careful, however, not to confuse the sense with the direction.

A VECTOR is represented by an oriented segment (an arrow) having a start point and an end point as endpoints.

The location in plane or space does not matter, two displacements of two distinct origin points can correspond to the same vector, it matters only its length, direction and sense.

Therefore, it is possible to draw it freely in the plane, parallel to itself.

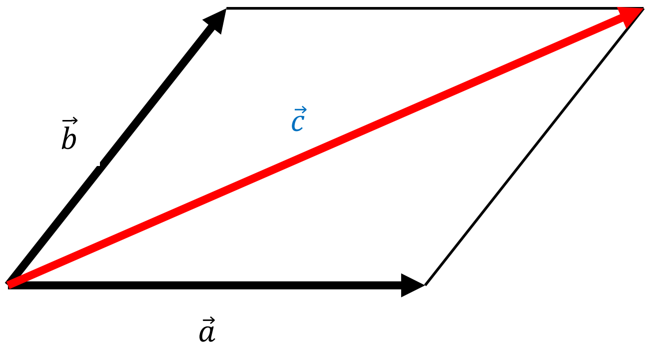
If *A* and *B* are two distinct points, **the vector has three characteristic elements:**

its direction (the line (AB))

its sense (there are two possible senses for the line (AB): from *A* to *B* or from *B* to *A*)

its magnitude (or its length, the length of the segment [AB])

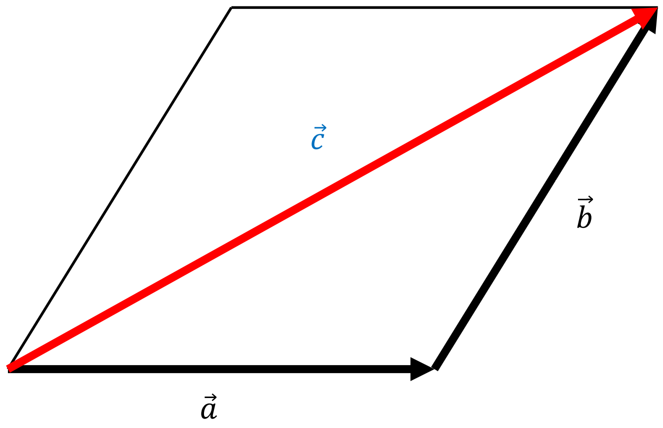
ADDITION (COMPOSITION) OF VECTORS a + b = c



The addition (composition) of vectors is done according to the parallelogram rule.

The sum of two vectors is equal to the diagonal of the parallelogram whose sides are the two vectors.

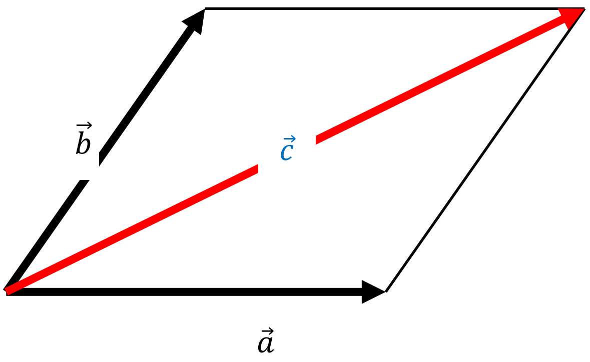
TRIANGLE RULE OF VECTOR ADDITION:



The vectors are positioned so that the origin of the second and the end of the first coincide.

The sum of the vectors is equal to the vector connecting the origin of the first to the end of the second.

VECTOR SUBTRACTION

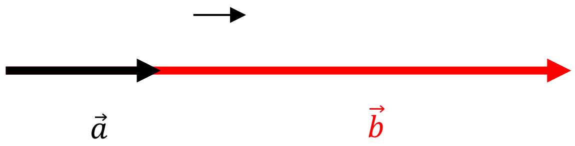


$\mathbf{a} + \mathbf{b} = \mathbf{c} \rightarrow \mathbf{b} = \mathbf{c} - \mathbf{a}$

The addition (composition) of vectors is done according to the parallelogram rule:

The sum of two vectors is equal to the diagonal of the parallelogram whose sides are the two vectors

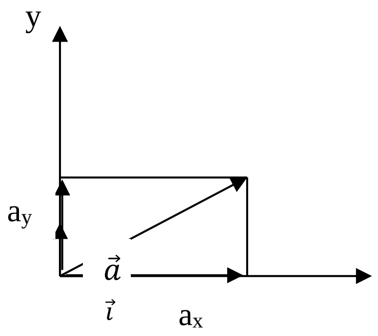
MULTIPLYING A VECTOR BY A SCALAR IS THE OPERATION OF MULTIPLYING THE VECTOR BY λ



If $\lambda>0$ the resulting vector has the same sense

If $\lambda<0$ the resulting vector is opposite

VECTOR DECOMPOSITION



Vectors can be decomposed in a plane into two components.

An important case is decomposition according to the directions of an orthogonal coordinate axis system (X, Y), called Cartesian system: $\mathbf{a} = a_x \mathbf{i} + a_y \mathbf{j}$

Here we have defined the unit vectors: i and j as vectors in the x and y directions having dimension 1.

It follows that a vector in the plane is equivalent to the definition of a pair of scalar quantities (a_x, a_y) called components of the vector along the axes Ox and Oy.

Leonard Euler (1707-1783)

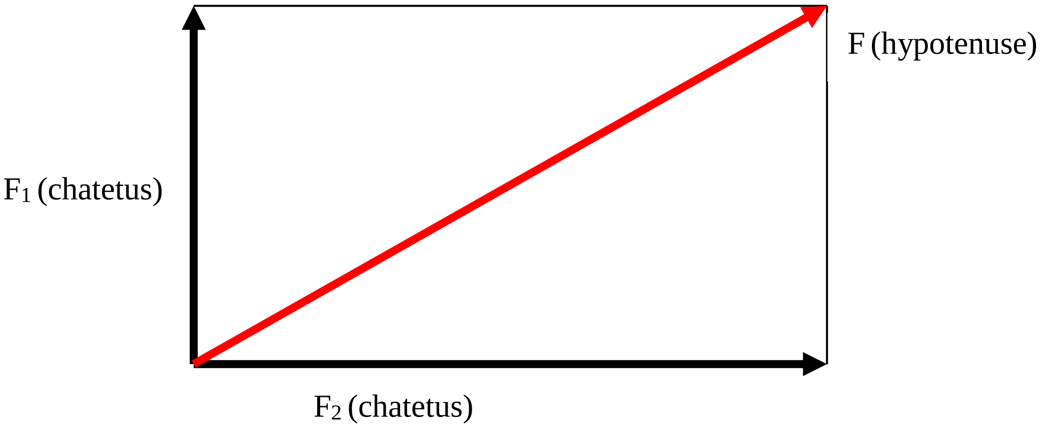
Swiss born mathematician

who lived in Saint Petersburg (Russia)

The time-dependent vector can be considered as a vector function which depends on a scalar (time).

Example: the position vector r(t) is a vector with fixed origin, the extremity of which moves along a curve called the trajectory.

APPLICATIONS: COMPOSITION OF PERPENDICULAR VECTORS



The numerical values of the two vectors are F1=3 and F2=4

According to the Pythagorean theorem:

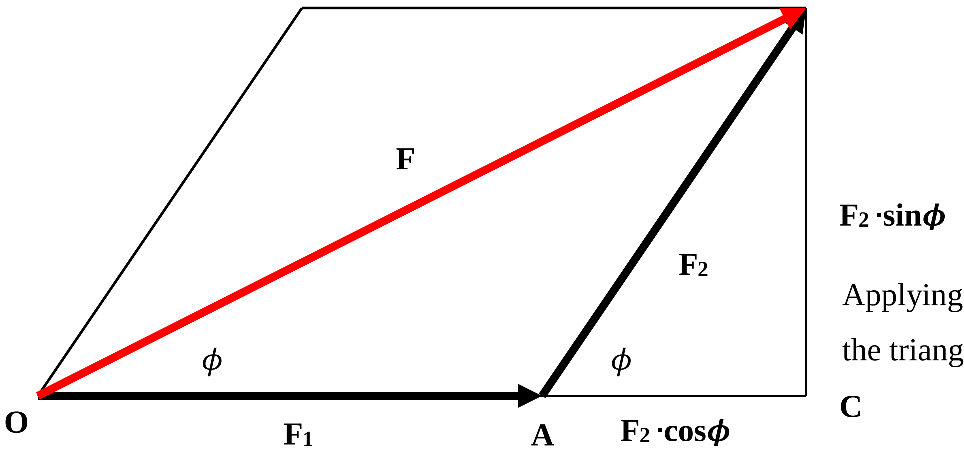
The square of the hypotenuse is equal to the sum of the squares of the other two sides, thus the value of the resultant is:

$$F = \sqrt{F_1^2 + F_2^2} = \sqrt{9+16} = \sqrt{25} = 5$$

The composition of the vectors in the general case is done by assembling the vector addition triangle OAB and the right triangle ABC in order to obtain the right triangle OBC.

Φ is the angle between vectors F1 and F2

B



Applying the Pythagorean theorem to the triangle OBC we get

$$
\begin{aligned}
F^2 &= (F_1 + F_2 \cos\varphi)^2 + F_2^2 \sin^2\varphi \\
&= F_1^2 + 2F_1F_2\cos\varphi + F_2^2(\cos^2\varphi + \sin^2\varphi) \\
&= F_1^2 + F_2^2 + 2F_1F_2\cos\varphi
\end{aligned}
$$

KINEMATICS AND DYNAMICS

KINEMATICS is a branch of mechanics that studies the motion of bodies, independent of their masses and the causes that produce the motion. From Fr. Cinematic. Source: DEX '09 (2009)

DYNAMICS is a branch of mechanics that studies the movement of bodies under the action of various forces. From Fr. Dynamic. Source: DEX '09 (2009)

KINEMATIC ELEMENTS

MOTION is in physics, a change in position of an object with respect to time.

There are two areas of physics that deal with the study of motion:

DYNAMICS - the part of physics that studies motion and the forces of motion, including their causes.

KINEMATICS - part of physics that studies motion without taking into account the causes of the forces that induce the motion.

Physical MOVEMENTS are defined by several parameters:

DISPLACEMENT is the difference between the initial and final positions of a displaced body.

TRAJECTOR is the path followed by a moving body, represented by the line described by its center of gravity.

In a rectilinear motion, the trajectory is a straight line.

In a curvilinear motion, the curved path is a line, it can also be a circle.

DISTANCE is the length of the path segment defined by the start point and end point of the body's motion.

VELOCITY is the measure of the change in position and direction of motion of a body as a function of time.

ACCELERATION is the measure of changes in speed of a body as a function of time.

Kinematics studies the general laws of motion of bodies without considering the causes of these motions or particular properties such as shape, size, etc.

The MATERIAL POINT is a real physical body whose size can be neglected in relation to other dimensions involved in this question.

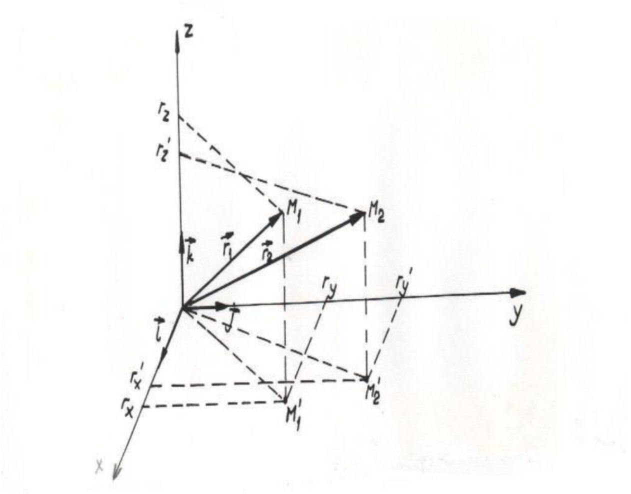
Any type of movement involves spatial intervals traveled in time intervals.

The study of motion requires the measurement of space-time intervals.

The measurement of an interval of space can only be done in relation to a certain frame of reference also called the body of reference.

In nature there are no absolute movements, only relative movements.

CARTESIAN COORDINATE SYSTEM



If point M is represented in a Cartesian coordinate system Oxyz by the position vector. Each coordinate axis corresponds to a versor or unit vector. The versors are located in the direction of the axes and have the property:

$$|\vec{\imath}| = |\vec{\jmath}| = |\vec{k}| = 1$$

The analytical expression for the position vector of the point M_1: $\vec{r}_1 = r_x.\vec{i} + r_y.\vec{j} + r_z.\vec{k}$

Since the coordinates r_x, r_y and r_z can depend on time, it is possible to write the following **PARAMETRIC EQUATIONS :**

$r_x = r_x(t)$ x=x(t)
$r_y = r_y(t)$ or y=y(t)
$r_z = r_z(t)$ z=z(t)

By eliminating time from the parametric equations we can obtain

TRAJECTIVE EQUATION : z = z (x,y)

VELOCITY - Cartesian coordinate system

The velocity of the material point in the Cartesian coordinate system is expressed by the following definition:

Velocity is the variation of coordinates with time.

$$\vec{v} = \frac{d\vec{r}}{dt}$$

$$\vec{v} = v_x\vec{i} + v_y\vec{j} + v_z\vec{k}$$

$$\vec{v} = \dot{r}_x\vec{i} + \dot{r}_y\vec{j} + \dot{r}_z\vec{k}$$

$[v]_{SI}$ = m/s   where [v]=km/h = 1000m/3600s

ACCELERATION - CARTESIAN COORDINATE SYSTEM

The ACCELERATION of the material point in the Cartesian coordinate system is expressed by definition as follows:

ACCELERATION is the change in speed over time.

$[a]_{SI} = m/s^2$, $[a]_{SI} = m{\cdot}s^{-2}$

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d^2\vec{r}}{dt^2}$$

$$\vec{a} = a_x \cdot \vec{i} + a_y \cdot \vec{j} + a_z \cdot \vec{k}$$

$$\vec{a} = \dot{v}_x \cdot \vec{i} + \dot{v}_y \cdot \vec{j} + \dot{v}_z \cdot \vec{k}$$

$$\vec{a} = \ddot{r}_x \cdot \vec{i} + \ddot{r}_y \cdot \vec{j} + \ddot{r}_z \cdot \vec{k}$$

FORCE - CARTESIAN COORDINATE SYSTEM

FORCE is the product of mass and acceleration.

The force exerted on the material point is a Newtonian force.

Knowing the mass m of the material point and applying the fundamental principle (principle 2 of mechanics), we will have the following relations: $\vec{F} = m \cdot \vec{a}$

$$\vec{F} = m \cdot a_x \cdot \vec{i} + m \cdot a_y \cdot \vec{j} + m \cdot a_z \cdot \vec{k}$$

$$F_x = m \cdot a_x$$

$$F_y = m \cdot a_y$$

$$F_z = m \cdot a_z$$

CONCLUSION:

Knowing the position vector of a material point and inevitably the parametric equations and the equation of the trajectory, one can determine the velocity, acceleration and type of force acting on it.

CARTESIAN COORDINATE SYSTEM. REVERSE METHOD

Knowing the type of force acting on the material point, it is possible to determine the equation of the path along which it moves.

$$\vec{F} = m \cdot \vec{a}; \vec{a} = \frac{\vec{F}}{m}$$

From **the definition of acceleration** : $\vec{a} = \frac{d\vec{v}}{dt}$

$$d\vec{v} = \vec{a} \cdot dt$$

if we separate the variables $d\vec{v} = \vec{a} \cdot dt$

and integrate using the initial conditions.

it can be observed what happens at t_0 and t, at v_0 and v

After doing an addition for all the terms, the following relations are obtained:

$$\int_{\vec{v_0}}^{\vec{v}} d\vec{v} = \int_{t_0}^{t} \vec{a} \cdot dt \Rightarrow \vec{v} - \overrightarrow{v_0} = \int_{t_0}^{t} \vec{a} \cdot dt$$

The velocity law has the following formula: $\vec{v} = \overrightarrow{v_0} + \int_{t_0}^{t} \vec{a} \cdot dt$

From the definition of velocity $\vec{v} = \frac{d\vec{r}}{dt}$

if we separate the variables $d\vec{r} = \vec{v} \cdot dt$

and integrate the coordinates on the left and the time on the right using the initial conditions:

$$\int_{\vec{r_0}}^{\vec{r}} d\vec{r} = \int_{t_0}^{t} \vec{v} \cdot dt \Rightarrow \vec{r} - \overrightarrow{r_0} = \int_{t_0}^{t} \vec{v} \cdot dt$$

THE LAW OF MOTION $\overrightarrow{r(t)} = \overrightarrow{r_0} + \int_{t_0}^{t} \vec{v} \cdot dt$ and

$$x(t) = x_0 + \int_{t_0}^{t} v_x \cdot dt$$

$$y(t) = y_0 + \int_{t_0}^{t} v_y \cdot dt$$

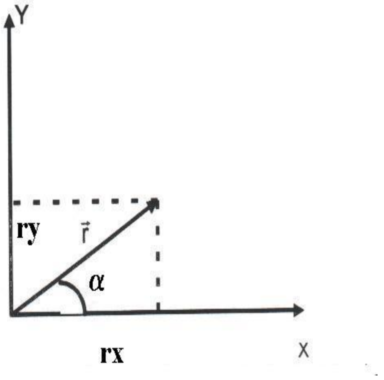
$$z(t) = z_0 + \int_{t_0}^{t} v_z \cdot dt$$

When we remove time from the parametric equations we get the trajectory equation: $z = z(x, y)$

The position vector $\vec{r} = x \cdot \vec{i} + y \cdot \vec{j} + z \cdot \vec{k}$

THE POLAR COORDINATE SYSTEM IN ONE PLANE

In the xOy polar coordinate system, the material point M is considered, characterized by the parametric equations: $\alpha = \alpha(t)$, $r = r(t)$



$r = r(\alpha)$ - Trajectory equation

The relationship between the Cartesian coordinate system and the polar coordinate system is:

$$x = r \cdot \cos\alpha$$
$$y = r \cdot \sin\alpha$$

$$\vec{r} = x \cdot \vec{i} + y \cdot \vec{j}$$
$$\vec{r} = r \cdot \cos\alpha \cdot \vec{i} + r \cdot \sin\alpha \cdot \vec{j}$$

The position vector has the following form: $\vec{r} = r \cdot \cos\alpha \cdot \vec{i} + r \cdot \sin\alpha \cdot \vec{j}$

THE RADIAL UNIT VECTOR: $\vec{i} \cdot \cos\alpha + \vec{j} \cdot \sin\alpha = \vec{\rho}$

THE UNIT TANGENT VECTOR: $-\vec{i} \cdot \sin\alpha + \vec{j} \cdot \cos\alpha = \vec{n}$

VELOCITY

By definition, velocity is equal to: $\vec{v} = \frac{d\vec{r}}{dt} = \dot{\vec{r}}$

with the position vector: $\vec{r} = r \cdot \cos\alpha \cdot \vec{i} + r \cdot \sin\alpha \cdot \vec{j}$

and the velocity vector:

$$\vec{v} = \dot{\vec{r}} = \dot{r} \cdot \cos\alpha \cdot \vec{i} - r \cdot \dot{\alpha} \cdot \sin\alpha \cdot \vec{i} + \dot{r} \cdot \sin\alpha \cdot \vec{j} + r \cdot \dot{\alpha} \cdot \cos\alpha \cdot \vec{j}$$
$$\vec{v} = \dot{r} \cdot \left(\vec{i} \cdot \cos\alpha + \vec{j} \cdot \sin\alpha\right) + r \cdot \dot{\alpha} \cdot \left(-\vec{i} \cdot \sin\alpha + \vec{j} \cdot \cos\alpha\right)$$

VELOCITY in the POLAR COORDINATE SYSTEM in one plane is: $\vec{v} = \dot{r} \cdot \vec{\rho} + r \cdot \dot{\alpha} \cdot \vec{n}$

The radial component of the velocity $\dot{r} = v_r$

Tangential component of velocity $r \cdot \dot{\alpha} = v_t$

Then the velocity vector is: $\vec{v} = v_r \cdot \vec{\rho} + v_t \cdot \vec{n}$

Notations:
Linear coordinate – **r**
angular coordinate **-α**

linear velocity: $\dot{r} = \frac{d\vec{r}}{dt}$ -
It is the variation of the coordinate with time

angular velocity : $\dot{\alpha} = \frac{d\alpha}{dt}$
It is the time-varying angle

Linear acceleration $\ddot{\vec{r}} = \frac{d^2\vec{r}}{dt^2}$
It is the 2nd order variation of distance with time

Angular acceleration $\ddot{\alpha} = \frac{d^2\alpha}{dt^2}$
It is the 2nd order variation of the angle with time

Acceleration is the first-order variation of velocity with time $\vec{a} = \dot{\vec{v}}$

The following calculations are made: $\vec{v} = \dot{\vec{r}} = \dot{r}\cdot\cos\alpha\cdot\vec{i} - r\cdot\dot{\alpha}\cdot\sin\alpha\cdot\vec{i} + \dot{r}\cdot\sin\alpha\cdot\vec{j} + r\cdot\dot{\alpha}\cdot\cos\alpha\cdot\vec{j}$

$\vec{a} = \dot{\vec{v}} = \ddot{r}\cdot\cos\alpha\cdot\vec{i} - \dot{r}\cdot\dot{\alpha}\cdot\sin\alpha\cdot\vec{i} - \dot{r}\cdot\dot{\alpha}\cdot\sin\alpha\cdot\vec{i} - r\cdot\ddot{\alpha}\cdot\sin\alpha\cdot\vec{i} - r\cdot\dot{\alpha}^2\cdot\cos\alpha\cdot\vec{i} +$

$+\ddot{r}\cdot\sin\alpha\cdot\vec{j} + \dot{r}\cdot\dot{\alpha}\cdot\cos\alpha\cdot\vec{j} + \dot{r}\cdot\dot{\alpha}\cdot\cos\alpha\cdot\vec{j} + r\cdot\ddot{\alpha}\cos\alpha\cdot\vec{j} - r\cdot\dot{\alpha}^2\cdot\sin\alpha\cdot\vec{j}$

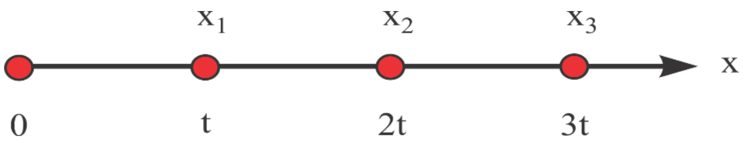
After performing the previous calculations we obtain the final form of the **acceleration:** $\vec{a} = \left(\ddot{r} - r\cdot\dot{\alpha}^2\right)\cdot\vec{\rho} + \left(2\cdot\dot{r}\cdot\dot{\alpha} + r\cdot\ddot{\alpha}\right)\cdot\vec{n}$

Where we have the following components:
The radial unit vector: $\vec{\rho} = \vec{i}\cdot\cos\alpha + \vec{j}\cdot\sin\alpha$
The unit tangent vector: $\vec{n} = -\vec{i}\cdot\sin\alpha + \vec{j}\cdot\cos\alpha$
Radial component of acceleration: $2\cdot\dot{r}\cdot\dot{\alpha} + r\cdot\ddot{\alpha} = a_n$
Tangential component of acceleration: $\ddot{r} - r\cdot\dot{\alpha}^2 = a_r$
The acceleration vector: $\vec{a} = a_r\cdot\vec{\rho} + a_n\cdot\vec{n}$
The acceleration module: $a = \sqrt{a_r^2 + a_n^2}$

If the material point has mass m, then the force exerted on the mass point has the expression: $\vec{F} = m\cdot\vec{a}$ or $\vec{F} = m\cdot(a_r\cdot\vec{\rho} + a_n\cdot\vec{n})$

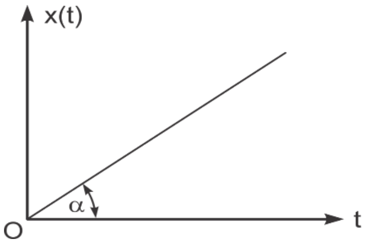
TYPES OF MOTION

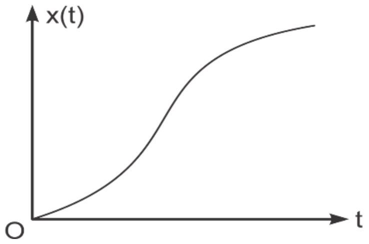
UNIFORM LINEAR MOTION



$$\frac{x_1}{t} = \frac{x_2}{2 \cdot t} = \frac{x_3}{3 \cdot t} = \cdots = \text{const} \quad ; \quad x_i = v \cdot i \cdot t$$

NON-UNIFORM LINEAR MOTION



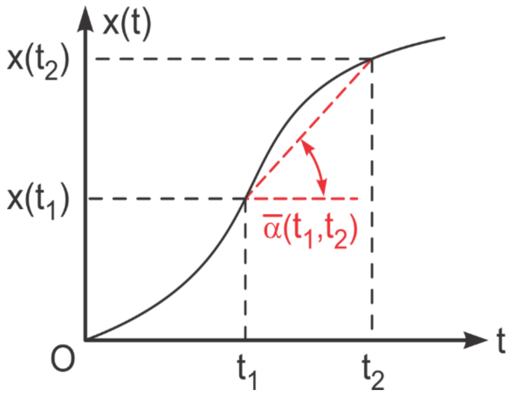


The displacement x(t) is a function of time and velocity (v) does not depend on time.

$$v = \frac{dx(t)}{dt} = \frac{x(t)}{t} = const$$

Displacement x(t) and velocity v(t) are functions of time: $v = \dfrac{dx(t)}{dt}$

Average velocity. Instantaneous velocity



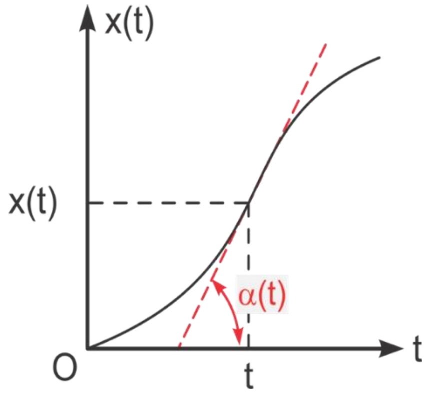
Average speed $x(t_1, t_2)$ in the time interval (t_1, t_2).

$$\bar{v}(t_1, t_2) = \frac{x(t_2) - x(t_1)}{t_2 - t_1}$$

Distance (Δx) traveled in the interval of time Δt

$$\Delta x = \bar{v}(t_1, t_2) \cdot \Delta t$$

The instantaneous velocity v(t) at time t is given by the formula: $v(t) = \dfrac{dx(t)}{dt} = \dot{x}(t)$



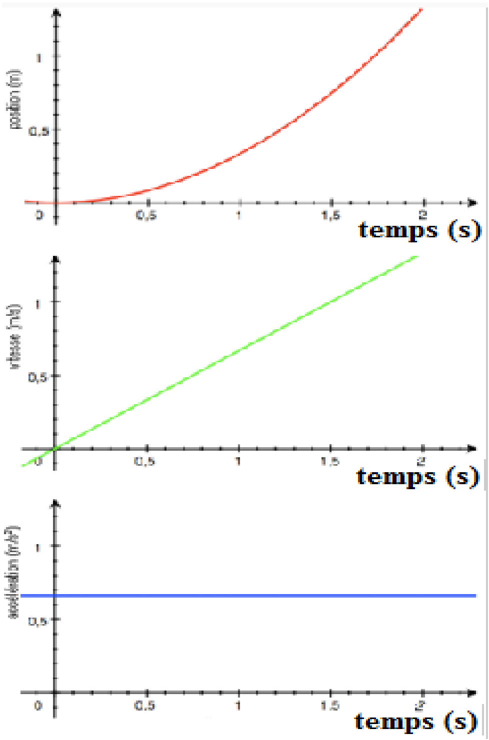
The distance traveled Δx (t_1, t_2), at the time interval Δt = $t_2 - t_1$

$$\Delta x(t_1, t_2) = \int_{t_1}^{t_2} v(t) \cdot dt$$

NON-UNIFORM LINEAR MOTION WITH VARIABLE VELOCITY (NON-ZERO ACCELERATION)

The change in velocity per unit time is called acceleration.

ACCELERATION is the derivative of speed in relation to time.



$$a(t) = \frac{dv(t)}{dt} = \frac{d^2x(t)}{dt^2}$$
$$a(t) = \dot{v}(t) = \ddot{x}(t)$$

Uniform accelerated motion:

a > 0

Uniform decelerated motion:

a < 0

$< a >_{SI} = m/s^2$

If the motion is rectilinear and accelerated, the acceleration is constant over time and we have a uniformly varied rectilinear motion (a=const).

$$a = const$$
$$v(t) = v(t_0) + a \cdot t - velocity\ law$$
$$x(t) = x(t_0) + \frac{1}{2} \cdot a \cdot t^2 \quad - displacement\ law$$

By combining the two relations, **Galileo relation** was obtained $\boxed{v^2 = v_0^2 + 2 \cdot a \cdot d}$

In kinematics, a **UNIFORMLY ACCELERATED RECTILINEAR MOTION** is a motion whose acceleration is constant.

Abbreviations are sometimes used

UARM - uniformly accelerated rectilinear motion

UDRM - uniformly decelerated rectilinear motion

UVRM - uniformly varied rectilinear motion

EQUATIONS OF MOTION

Assume the motion is along the *x- axis* .

$$\begin{cases} a(t) = \ddot{x} = \text{constante} \\ v(t) = \dot{x} = v_0 + at \\ x(t) = x_0 + v_0 t + \frac{1}{2}at^2. \end{cases}$$

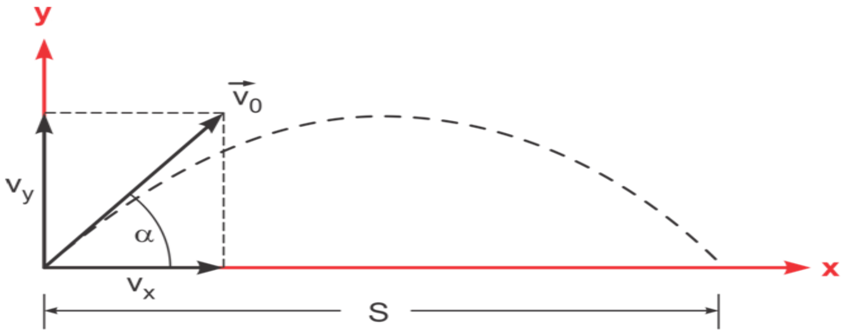
From these formulas, it can be deduced the relationship between acceleration, velocity variation and distance traveled (x-x_0)

$$v^2 = v_0^2 + 2a(x - x_0)$$

OBLIQUE PROJECTILE MOTION OF A MATERIAL POINT IN GRAVITATIONAL FIELD

- It is composed of a rectilinear and uniform horizontal motion

and a vertical projectile.



At each time t, the coordinates x(t) and y(t) of the material point are expressed as follows:

$$x(t) = t \cdot v_0 \cdot \cos\alpha$$

$$y(t) = t \cdot v_0 \cdot \sin\alpha - \frac{1}{2} \cdot g \cdot t^2$$

Eliminating t from the two equations we obtain:

$$y = \frac{v_0^2 \cdot x \cdot 2 \cdot \sin\alpha \cdot \cos\alpha - g \cdot x^2}{2 \cdot v_0^2 \cdot \cos^2\alpha}$$

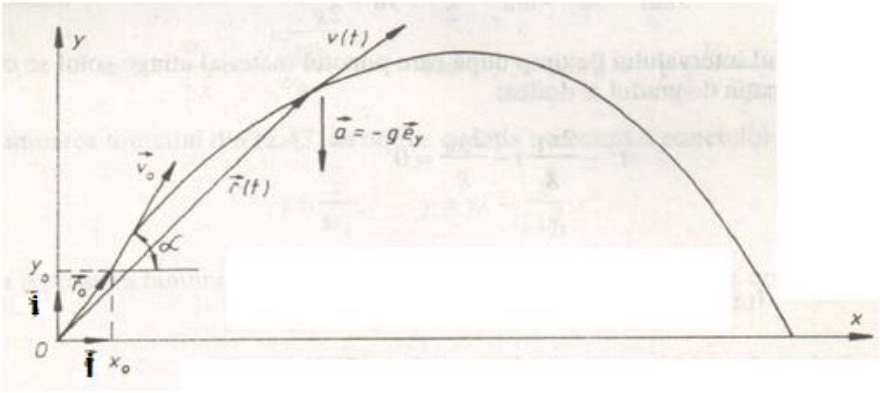
$$if \quad y \to 0,\ then\ x \to \begin{Bmatrix} 0 \\ S \end{Bmatrix} \quad \Rightarrow S = \frac{v_0^2 \cdot \sin(2 \cdot \alpha)}{g}$$

In the gravitational field at such distances all bodies have the same acceleration. This conclusion is the result of numerous experimental data of Galileo Galilei (1564-1642).

If time t is equal to 0, the material point vector is r and its initial velocity v is: C1 = v_0, C2 = r_0,

$$\vec{r}(t) = \vec{r}_0 + \vec{v}_0 t - \frac{gt^2}{2}\vec{j}$$

Thus $\vec{v}(t) = \vec{v}_0 - gt\vec{j}$



Laws of motion on the axes Ox and Oy:

$$x(t) = x_0 + v_0 t \cos\alpha$$

$$y(t) = y_0 + v_0 t \sin\alpha - \frac{gt^2}{2}$$

$$v_x(t) = v_x = v_0 \cos\alpha$$

The time after which the body reaches a maximum height

VERTICAL PROJECTILE MOTION

For the following case: x=0 and α= π/2

$$y(t) = y_0 + v_0 t \sin\alpha - \frac{gt^2}{2}$$

$$v_x = v_0 - gt = 0$$

$$t_0 = \frac{v_0}{g} \text{ The time when the body possesses the maximum height}$$

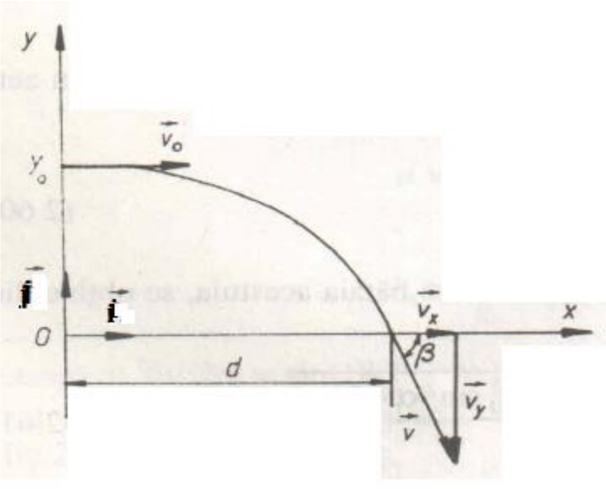
$$y_{\max} = y_0 + v_0 t_0 - \frac{g t_0^2}{2} = y_0 + \frac{v_0^2}{2g} - \text{Maximum height}$$

HORIZONTAL THROWING WITH VELOCITY VO FROM HEIGHT H

Case for which x=0 and α=0

$$x(t) = v_0 t$$

$$y(t) = y_0 + \frac{gt^2}{2}$$



Time after which the material point touches the ground :

$$y_0 = \frac{gt^2}{2}$$

$$t = \sqrt{\frac{2.y_0}{g}}$$

Distance traveled horizontally from the material point:

$$d = v_0 t = v_0 \sqrt{\frac{2v_0}{g}}$$

COMPONENTS OF VELOCITY WHEN THE MATERIAL POINT REACHES THE EARTH'S SURFACE

$$v_x = v_0$$

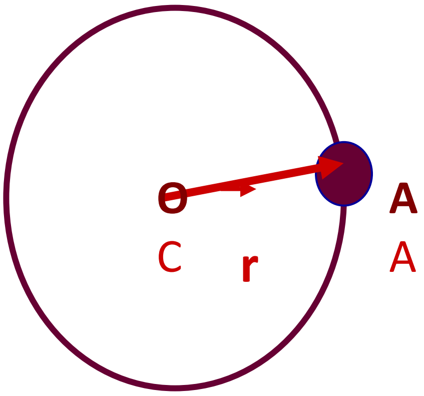
$$v_y = -yt = -g\sqrt{\frac{2y_0}{g}} = -\sqrt{2gy_0}$$

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{v_0^2 + 2gy_0}$$

UNIFORM CIRCULAR MOTION

It is the motion of the material point on a circle when its velocity has a constant modulus. The material point describes equal arcs in equal time intervals.

CHARACTERISTIC PHYSICAL QUANTITIES

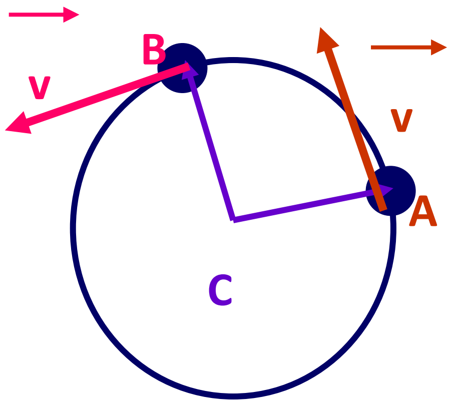


Radius vector (r) - the position vector of the material point drawn from the center of the circle outward

Period (T) - the time in which the material point travels the entire length of the circle.

Frequency (ν) - the number of complete rotations made by the material point per unit of time: $\nu = \frac{1}{T}$

$$[\nu]_{SI} = \frac{1}{s}\left(\frac{rot}{s}\right)$$



Linear speed (v) - the speed of the material point on the trajectory having the modulus equal to the length of the circular arc traveled per unit of time: $v = \frac{AB}{\Delta t}$

Angular velocity (ω) - this is the central angle described by the vector per unit of time: $\omega = \frac{\Delta\theta}{\Delta t}$ and the unit is: $[\omega]_{SI} = \frac{rad}{s}$

Normal acceleration (centripetal) - this is the change in the speed of the material point per unit time:

$$a = \frac{\Delta v}{\Delta t}$$

$$a = \frac{v^2}{r} = \omega^2 r$$

$$a = -\omega^2 r$$

Law of uniform circular motion: $\theta = \theta_0 + \omega(t - t_0)$

The relationship between angular velocity (ω), period (T), frequency (ν): $\omega = \frac{2\pi}{T} = 2\pi\nu$

The relationship between linear velocity (v) and angular velocity (ω): $\vec{v} = \vec{\omega} \times \vec{r}$

and the value or modulus of the vector: $v = \omega r$

Centripetal force is the force that exerted on the material point, causes uniform circular motion.

Centripetal force can be the gravitational force exerted on the Earth by the Sun or the force exerted by the Earth on the Moon.

$$F = m\omega^2 r = m\frac{v^2}{r}$$

Or $F = -m\omega^2 r$

The frictional force applied to the tires by the circular path.

The electric force exerted by the nucleus on the electrons of the atom .

The force exerted by the magnetic field on an electric charge moving in a field is called the Lorentz force.

The tensile strength of a spring attached to a body

CENTRIFUGAL FORCE

In an inertial reference frame, when we have a centrifugal force, we automatically have a centripetal force.

Examples:

1) CENTRIPET FORCE - this is the force exerted by the Sun on the Earth

2) CENTRIFUGAL FORCE - this is the force exerted by the Earth on the Sun

In the case of CENTRIFUGAL INERTIA FORCE appearing in a non-inertial frame of reference we have the following example:

In curves, bodies in accelerated motion tend to move outside the curve.

Effects and applications of centrifugal force

Centrifuge for extracting honey

Centrifugal washing machine

When turning, cyclists and motorcyclists lean towards the center of the corner curve: $tg\alpha = \frac{v^2}{gR}$ to avoid falling.

In curves the outer rail is raised to avoid the uneven application of forces on the rails and consequently overturning of the wagons.

To avoid skidding of cars on the route, the road is inclined from horizontal angle to horizontal angle:

$$tg\alpha = \frac{v^2}{gR}$$

Centrifugal separator

Centrifugal

centrifugal fan

The effect of centrifugal force is the flattening of the Earth at the poles.

CENTRIFUGATION

Centrifugation is a process of gravitational separation of suspensions in water at accelerations greater than the gravitational acceleration.

In the case of centrifugation, a high sedimentation speed is obtained, which leads to the separation of a large mass of suspensions per unit of time.

Through centrifugation, more compact concentrates with a higher solids content are obtained.

Due to the high installation cost and energy consumption, this process is preferably applied to wastewater containing high concentration suspensions and for sludge concentration.

CENTRIFUGATION is a process of separating compounds in a mixture according to their difference in density by subjecting them to centrifugal force.

The mixture to be separated may consist of either two liquid phases or solid particles suspended in a fluid.

The device used is a high-speed rotating machine called **a CENTRIFUGE.**

THE PRINCIPLE OF CENTRIFUGATION

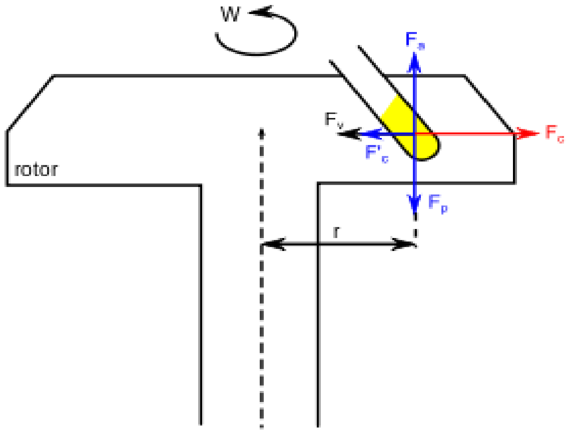


Schéma des différentes forces s'appliquant sur le composé à centrifuger

The separation of compounds from a mixture can be achieved by **DECANTATION,** under action of the only good results and is therefore often ineffective.

Therefore, it is more efficient to use centrifugation.

During this separation operation, the compounds in the fluid located at a distance r from the axis of rotation are subjected to different forces

Descent gravitational force - Fp

The upward force of Archimedes - Fa

A frictional force - Fv

Centripetal force - F'c

Centrifugal force - Fc

The separation takes place through the action of the centrifugal force Fc on the compounds.

This **centrifugal force** , expressed in newtons, is given by the relationship :

$F_c = mr\omega^2$ in N or ($kg.m/s^2$) where :

- m represents the mass of the compound to be separated
- r is the distance of the tube from the spin axis of the centrifuge

Angular velocity ω expressed in radians per second or revolutions per minute (rpm).

The ratio between the centrifugal force Fc and Fp is called **the intensity of artificial gravity** and is expressed in "g".

The values used in centrifugation are about 400 to 10,000g, which corresponds to rotational speeds of the order of 2,000 to 10,000 rotations (or revolutions)/min depending on the radius of the rotors.

Some **applications, such as** the separation of **biological macromolecules** (proteins, nucleic acids), require **the ultracentrifugation method** developed by **Svedberg** that uses very high intensities of artificial gravity of the order of 200,000 g, and which therefore requires rotation speeds of several tens of thousands of revolutions per minute.

CENTRIFUGATION - UTILISATION

In everyday life: centrifuging salad (eg: salad spinner), centrifuging laundry (eg: washing machine), extracting juice from fruits and vegetables;

In the environment: drying sludge for wastewater treatment;

In the food industry: separation of milk cream (defatting), removal of particles from beer or wine (clarification), extraction of oils and fats (olive oil extraction), honey extraction (beekeeping),

In laboratories: for the recovery of a precipitate, for the separation of the elements formed in the blood (red blood cells, white blood cells, platelets suspended in the blood plasma), the separation of cellular compounds for biochemical or molecular study.

In gold panning: to separate the gold from the gold sands with a pan.

In the nuclear field: uranium enrichment with the light isotope U235;

In the foundry for the production of cylindrical parts;

Centrifugal decanters with a horizontal axis with continuous operation are usually used for waste water.

They consist of a cylindrical-conical rotating body in which, in turn, a worm rotates, at a somewhat lower speed.

Aqueous suspensions are introduced through the axis of the body and projected onto the internal face of the centrifuge body wall.

Solids deposited on the wall due to centrifugal forces are scraped and pushed by the screw over the conical area of the centrifuge.

The clarified liquid called centrate is discharged at the opposite end of the centrifuge.

The depth of the liquid layer above the centrifuge wall is fixed by means of adjustable annular overflows through which the clarified liquid is discharged. Conveying the concentrate into the cone is a delicate task due to the high shear forces involved and the possibility of splashing of the clarified liquid, which can drive solid material back into the centrifuge body.

Thus, the concentrate obtained by centrifugation contains more than 50% dry substance compared to the sludge obtained by other separation methods whose concentration is between 4% and 10%.

SEDIMENTATION

CENTRIFUGATION is a hydrodynamic operation through which heterogeneous mixtures can be separated.

This is done using the centrifugal force that occurs at high rotational speed.

The devices with which it is done are generally called CENTRIFUGE.

Centrifuges are characterized by elements that rotate at a high speed. In some cases, centrifuges receive special names, largely determined by the operation performed: separator, clarifier, concentrator, etc.

Centrifuges mainly consist of a drum that rotates at high speed around a vertical or horizontal axis.

The separation of heterogeneous mixtures under the influence of centrifugal force is carried out according to the SEDIMENTATION PRINCIPLE or the FILTRATION PRINCIPLE.

In the first case, the centrifuge drum is not perforated, so the separation takes place by sedimentation in the centrifugal field of the solid particles that accumulate on the wall of the drum, arranging themselves in layers depending on the difference in density and clarity. the liquid remains in the centrifuge.

Centrifugation according to the principle of sedimentation sometimes has special names depending on the technological stage carried out, such as:

- **clarification** (removal of solid impurities from a liquid),
- **concentration** (concentration of solid particles in a solid-liquid mixture)

In the second case, the walls of the drum are perforated and covered with a filter. Thus, under the action of centrifugal force, the suspension moves to the periphery of the drum, where the solid particles settle on the filter cloth and the liquid passes through the sediment layer. Solid particles are filtered and removed through the holes in the drum. It should be taken into account that through the filtration process, the liquid passes through the filter surface under the effect of centrifugal force, and the solid particles also entrained by the centrifugal force are retained on the surface of the filter layer as in the case of sedimentation.

Three main phases occur, namely: the formation of the precipitate, its compaction and the elimination of the liquid retained by capillary and molecular forces in the pores of the sediment.

The first stage of filtration is very similar to sedimentation, but in centrifugal filtration the pressure of the fluid passing through the sediment is higher and the removal of moisture more intense.

The phases of compaction and elimination of the liquid retained by capillary and molecular forces in the pores of the sediment do not exist in ordinary filtration (sedimentation).

The phase of removal of liquid retained in sediment pores is very similar to a mechanical drying process.

FILTRATION

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The phase of removal of liquid retained in sediment pores is very similar to a mechanical drying process.

Therefore, under the influence of centrifugal force, filtration can remove more liquid and drier sediments can be obtained, compared to ordinary filtration.

Afterwards, a washing of the precipitate can be done.

The duration **of the filtration phases** under the effect of centrifugal force depends on a certain number of factors.

In dilute slurries, the sediment formation step is very important, while in concentrated slurries, this step is absent because settling occurs instantaneously.

It should be noted that sedimentation under the influence of centrifugal force differs from settling under the influence of gravity.

The rate of sedimentation in the gravitational field of particles having the same size and density can be considered constant throughout the container in which the sedimentation occurs because the gravitational acceleration is independent of the particle's position.

The effect of centrifugal force is influenced by a number of factors for both sedimentation and filtration separation.

The main factors involved in the process are:

- value of centrifugal force
- the nature of the material to be separated
- the material from which the machine is made

Separation is caused by centrifugal force resulting from the rotation of a body around its axis.

The centrifugal force resulting from the movement of a particle along a curved path is expressed by the equation: $F_c = \frac{m.w^2}{R}$

Or:

Fc - centrifugal force, N;

m - particle mass, kg;

w - peripheral speed, m / s;

R - radius of rotation, m;

Given the angular velocity ω, the relationship becomes: $Fc = m\omega^2 R$

THE PRINCIPLES OF NEWTONIAN MECHANICS

Classical mechanics is based on three fundamental principles established by Issac Newton (1642-1727) in his famous work **"Philosophy Naturalis Principia Mathematica"** published in 1686.

The successes of Newtonian mechanics were so great that it was considered especially in the 19th century that to **explain any physical phenomenon is to reduce it to a mechanical process that can be understood on the basis of Newton's principles.**

The experimental data led to the following conclusions:

A body undergoing the action of other bodies changes its velocity, i.e. receives a certain acceleration.

A body subjected to the action of other bodies deforms by changing its size and shape.

The quantitative description of these phenomena is done by introducing **the concept of force**: **any action exerted on a body that gives it an acceleration or produces a deformation is called FORCE.**

Experimental results show that for a given body the ratio between force and acceleration is a constant characteristic of this body, also called **inertial mass.**

In classical mechanics, **the inert mass will have the following fundamental properties:**

Inert mass m is an additive physical quantity, that is, the mass of a body which is equal to the sum of the masses of its components.

The inertial mass m is a constant physical quantity characteristic of the body considered independent of the body's state of motion.

The forces are classified as follows:

Forces distributed throughout the volume of bodies and proportional to the masses of their components, such as gravitational forces.

Forces applied or concentrated at a point on the body. These forces are transmitted from one part of the body to another due to the mutual interactions between the corresponding parts, always producing a deformation.

Force, as a measure of the interactions between bodies, is considered to be the cause of a particular body having a particular acceleration. But it would seem that this statement is not correct, because the acceleration of a body also depends on the reference frame.

It follows that the acceleration of a body can have two origins:

-the interaction between the considered body and other bodies

- properties of the reference frame

The solution to the fundamental problem of dynamics is based on several fundamental principles, the first three of which were proposed by Isaac Newton (1642).

NEWTON'S PRINCIPLES OF CLASSICAL MECHANICS

PRINCIPLE OF INERTIA (the first principle of dynamics):
A body on which no force acts, maintains its state of rectilinear and uniform motion or of relative rest.

The principle of proportionality between force and acceleration (SECOND DYNAMIC PRINCIPLE) can be stated as follows:
"A force acting on a body gives it an acceleration proportional to the force and inversely proportional to the mass of the body."
Quantitative writing: $F = m \cdot a$
Can be expressed as follows:

$Fx = m.ax$
$Fy = m.ay$ *NEWTON equations*
$Fz = m.az$

THE LAW OF RECIPROCAL ACTIONS
(principle of action and reaction) states that the forces of interaction between two bodies are of equal magnitude and opposite direction, i.e.
$F_{ij} = F_{ji}$ **(**$i \neq j$**); where**
F_{ij} **is the force with which body j acts on body i**
F_{ji} **is the force with which body i acts on body j**

PRINCIPLE OF INDEPENDENCE OF ACTION OF FORCES:
Each of the forces exerted on a body is independent of the existence of the other applied forces.

GALILEO'S PRINCIPLE OF CLASSICAL RELATIVITY reflects an important physical property of inertial referance frames:

"Any mechanical experiment performed in an inertial referance frame can demonstrate neither the rectilinear and uniform motion nor the relative state of rest of the referance frame with respect to other inertial referance frames".

An obvious form of this principle was given by Galileo in 1632:

"The laws of the phenomena remain unchanged in the uniform translation of the inertial referance frame in which these phenomena are studied, relative to any other inertial referance frame".

QUANTITY OF MOVEMENT IN CLASSICAL MECHANICS OR MOMENTUM

Definition in classical Newtonian mechanics

In classical mechanics, **the QUANTITY OF MOTION or MOMENTUM of a material point of mass m animated by a velocity in a given referance frame is defined as the product of mass and velocity** : $\vec{p} = m.\vec{v}$

It is therefore, like velocity, a vector quantity, whose **SI unit is kg · ms^{-1}**

This quantity is *additive*, thus for a material system composed of *N* particles, the total momentum (or *kinetic resultant*) of the system is defined by the following formula: $\vec{p} = \sum_{i=1}^{n} m\vec{v}_i$

FUNDAMENTAL THEOREMS OF MECHANICS

Momentum theorem is another form in which **the second law of dynamics can be stated**.

We introduce the momentum of the body with mass m: $\vec{p} = m\vec{v}$

$$\vec{F} = m\vec{a} = m\frac{d\vec{v}}{dt} = \frac{d}{dt}(m\vec{v}) = \frac{d\vec{p}}{dt}$$

The MOMENTUM VARIATION THEOREM can be expressed as follows:

"Force is equal to the change in momentum over time." $\vec{F} = \frac{d\vec{p}}{dt}$

The change in momentum of the material point is equal to the momentum of the force $d\vec{p} = \vec{F}.dt$

or

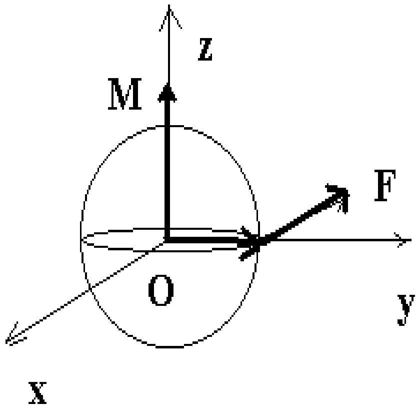
Impulse is the product of a constant force and its application time.

MOMENTUM CONSERVATION PRINCIPLE

In particular, if the resultant of the forces acting on the material point is zero ($\vec{F} = 0$), then the result is **the momentum conservation principle (law)** $\vec{p} = constant$

The principle (law) of conservation of **momentum of the material point is stated: if the resultant of the forces acting on the point is zero ($\vec{F} = 0$), then the system is in translational equilibrium and the momentum of the material point is preserved.** $\vec{p} = constant$

MOMENTUM OF FORCE



If a force acts on the body in the direction and the sense of the Ox axis,

the position vector where the force is applied is defined by: $\vec{r} = r_x\vec{i} + r_y\vec{j} + r_z\vec{k}$

Everything is represented in a Cartesian coordinate system.

Force vector is defined by: $\vec{F} = F_x\vec{i} + F_y\vec{j} + F_z\vec{k}$

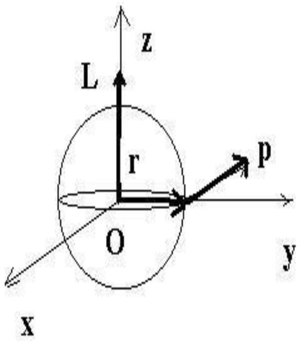
MOMENTUM OF FORCE can be expressed as follows:

$$\vec{M} = \vec{r} \times \vec{F} = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ r_x & r_y & r_z \\ F_x & F_y & F_z \end{vmatrix} = M_x.\vec{i} + M_y\vec{j} + M_z\vec{k}$$

And the norm is written: $\left|\vec{M}\right| = \left|\vec{r}\right|\left|\vec{F}\right|\sin\left(\vec{r},\vec{F}\right)$

Take a spinning pen and rotate as shown in the figure: r on F. Observe whether the vector M goes up or down.

CINEMATIC MOMENTUM



If the momentum acts on the body represented in a Cartesian coordinate system in the direction and sense of the Ox axis, then

the position vector of the point where the force is applied is defined by: $\vec{r} = r_x\vec{i} + r_y\vec{j} + r_z\vec{k}$

And **the momentum** (or the quantity of motion) is: $\vec{p} = p_x\vec{i} + p_y\vec{j} + p_z\vec{k}$

The vector quantity KINETIC MOMENTUM can be expressed as follows:

$$\vec{L} = \vec{r} \times \vec{p} = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ r_x & r_y & r_z \\ p_x & p_y & p_z \end{vmatrix} = L_x.\vec{i} + L_y.\vec{j} + L_z\vec{k}$$

The scalar quantity or the standard expression of the ANGULAR MOMENT can be written as follows: $|\vec{L}| = |\vec{r}||\vec{p}|\sin(\vec{r}, \vec{p})$

If the angular momentum is defined by: $\vec{L} = \vec{r} \times \vec{p}$

then the variation of angular momentum with respect to time is: $\frac{d\vec{L}}{dt} = \frac{d\vec{r}}{dt} \times \vec{p} + \vec{r} \times \frac{d\vec{p}}{dt}$

but: $\begin{matrix} \vec{v} = \frac{d\vec{r}}{dt} \\ \vec{F} = \frac{d\vec{p}}{dt} \end{matrix}$ It is the definition of velocity and the definition of force

And $\frac{d\vec{r}}{dt} \times \vec{p} = 0$ because the two vectors are positioned parallel

THEOREM OF VARIATION OF ANGULAR MOMENTUM

Using the definitions of force and velocity we obtain the following statement: **"The variation of angular momentum with respect to time is equal to the momentum of force".**

$$\frac{d\vec{L}}{dt} = \vec{r} \times \frac{d\vec{p}}{dt} = \vec{M}$$

THEOREM OF CONSERVATION OF ANGULAR MOMENTUM

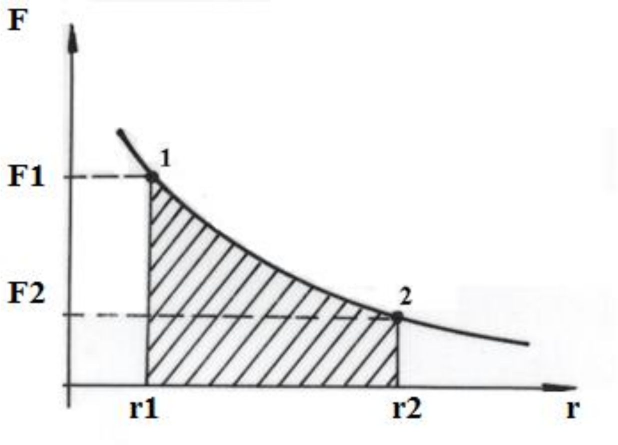
If the momentum of force is zero, then the variation of angular momentum is zero and the angular momentum is constant $\frac{d\vec{L}}{dt} = \vec{M}$

And the statement of the theorem of conservation of angular momentum is: $\vec{M} = 0 \quad d\vec{L} = 0 \quad \vec{L} = cons\tan t$

"If the momentum resulting from the forces acting on the system cancels, this means that, the system is in rotational equilibrium, thus the angular momentum of the system is conserved."

MECHANICAL WORK

The elementary mechanical work done by the force dF to move the material point from point 1 to point 2 is defined by the following relation: $dW = \vec{F}d\vec{r}$



Calculation of mechanical work for different types of forces

Mechanical work is defined by: $W_{12} = \int_{\vec{r}1}^{\vec{r}2} \vec{F}d\vec{r} = A_{12r2r1}$

In classical mechanics, work is also equal to the area of the figure formed by the force curve, the perpendiculars dropped to points 1 and 2 (the initial point and the final point) and the axes of motion.

The following formula can be also written for one direction: $W_{12} = \int_{x1}^{x2} Fdx$

SPECIAL CASES

Calculation of work in the case of ELASTIC FORCE

The vector quantity of the elastic force is: $\vec{F}_e = -k\vec{r}$

In one direction, the scalar quantity of the elastic force can be written:
Fe=-kx

The mechanical work is: $W_{12} = \int_{x1}^{x2} Fdx = \int_{x1}^{x2} -kxdx = -\frac{k}{2}\left(x_2^2 - x_1^2\right)$

General formula: $\int_{x1}^{x2} x^n dx = \frac{x^{n+1}}{n+1} \Big|_{x1}^{x2} = \frac{x_2^{n+1} - x_1^{n+1}}{n+1}$

CALCULATION OF MECHANICAL WORK IN THE CASE OF CENTRAL FORCE:

EXAMPLES OF CENTRAL TYPE FORCES :

Universal force of attraction: $F = \frac{km_1 m_2}{r^2}$

The force of attraction between two point charges.

Coulomb force: $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$

General form of central type forces

$$F = \frac{\alpha}{r^2}$$

$$\vec{F} = \frac{\alpha}{r^2}\frac{\vec{r}}{r}$$

For the forces of universal attraction: $\alpha = km_1 m_2$

For Coulomb forces: $\alpha = \frac{q_1 q_2}{4\pi\varepsilon_0}$

Mechanical work of central type forces:

$$dW_{12} = Fdr = \frac{\alpha}{r^2}dr$$

$$W_{12} = \int_{r1}^{r2}\frac{\alpha}{r^2}dr = -\alpha\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

CALCULATION OF MECHANICAL WORK IN THE CASE OF CONSTANT FORCE

In general, for a constant force : $\vec{F} = constant$

Elementary mechanical work has the following form: $dW = \vec{F}d\vec{r}$

The total work is written as follows: $W_{12} = \int_{\vec{r}1}^{\vec{r}2}\vec{F}.d\vec{r} = \vec{F}.(\vec{r}_2 - \vec{r}_1)$

The work does not depend on the shape of the path traveled between states 1 and 2 (initial position and final position of the path).

For the homogeneous gravitational force acting on the body of mass m $\vec{G} = m\vec{g} = mg\vec{k}$

The elementary mechanic work is: $dW = \vec{G}d\vec{r} = -mgdz$

Finally, we get the formula for **the total mechanical work:** $W_{12} - mg\int_{z1}^{z2}dz = mg(z_2 - z_1)$

The integral is a sign that shows that we collect all the values from the initial state to the final state.

CALCULATION OF WORK FOR FRICTION FORCE $F_f = \mu\ N$

If the material point moves from an initial position 1 to a final position 2 on a circle of radius r, the work done by the frictional force is: $W_{12} = \int_{r1}^{r2} F_f\, dr = -2.\pi.r.\mu\ mg$ **if the movement takes place on the circular arc.**

And for the distance (r2-r1): $W_{12} = \int_{r1}^{r2} F_f\, dr = \mu\ mg(r_2 - r_1)$

ENERGY

ENERGY is defined in physics as the ability of a system to produce work[1], causing motion or producing, for example, light, heat or electricity.

It is a physical quantity that characterizes the state of a system and is globally preserved during transformations.

Energy is expressed in joules (in the international system of units) or often in kilowatt-hours (kWh·h or kWh).

Energy is an essential concept in physics that has become clearer since the 19th century.

We find the concept of energy in all branches of physics:

- in mechanics;
- in thermodynamics;
- in electromagnetism;
- in quantum mechanics;
- in other disciplines, especially in chemistry.

FORMS OF ENERGY IN MECHANICAL PHYSICS

Mechanical physics considers two manifestations for energy:

- kinetic energy of a moving mass;
- the potential energy of the interaction forces acting between the systems.

When two systems interact, they exchange energy. During the interaction, the sum of energy changes in the first system is the opposite of the sum of energy changes in the second: there is conservation of energy.

For example, a balloon falling freely in the Earth's atmosphere will convert its gravitational energy into heat, transmitted into the air, through the frictional forces due to the electromagnetic force.
There is a conversion of the potential energy of the ball's gravitational force into kinetic energy and then into the kinetic energy of the air molecules (heat).

KINETIC ENERGY

(from Greek *ἐνέργεια / énergeia* "force in action" and *κίνησις / kinesis* "motion")
KINETIC ENERGY is the energy possessed by a body due to its motion relative to a certain reference frame. Its value therefore depends on the choice of this reference frame.
It is expressed in joules (J).
For a material point, the kinetic energy is equal to the work of the applied forces required to move the body from rest to its motion (if the reference frame chosen is not Galilean, it will be necessary to take into account the work of the inertial forces of training).
Consequently, the kinetic energy is generally not the first integral of the movement, except for the case where the work of the external and internal forces (for a system of material points) are zero during the movement.
A classic example of this type of situation is the case of the motion of an electric charge in a uniform magnetic field.

Kinetic energy - History

Gottfried Leibniz, thus opposing Descartes, who believed that momentum is always conserved, developed the idea of "living force" (*vis viva*), to which he assigned a value. The living force is therefore twice the kinetic energy.
"It is a long time ago that I corrected the doctrine of the conservation of momentum and put in its place something else absolute, just what is necessary, the absolute (living) force... It can be proved, by reason and experience, that it is the living force that is conserved..." (http://fr.wikipedia.org/wiki/%C3%89nergie_cin%C3%A9tique)

KINETIC ENERGY - DEFINITIONS

In non-relativistic cases (i.e. when velocities are small compared to the velocity of light in a vacuum),

$$M = \sum_i m_i$$

kinetic energy (in J) of a material point of mass *m* (in kg) moving with a velocity v (in ms $^{-1}$) in a specific reference frame is expressed as: $E_c = \frac{1}{2} m.v^2$

In the case of a material point

In the field of validity of Newtonian mechanics, the concept of kinetic energy can be easily demonstrated for a material point, a body considered as a point of constant mass *m.*

The case of a point system

In the case of a body that cannot be considered punctual, it can be assimilated to a system (of an infinity) material points of masses as *total body mass*.

Kinetic energy of the system of points can be defined as the sum of the kinetic energies associated with the material points that constitute the system: $E_c = \sum_i E_{c,i} = \sum_i \frac{1}{2} m_i . v_i^2$

This expression is general and does not prejudge the nature of the system, deformable or not.

KINETIC ENERGY- IN RELATIVE MECHANICS

In Einstein's theory of relativity (mainly used for velocities close to the speed of light, but valid for all velocities), kinetic energy is:

$$E_k = mc^2(\gamma - 1) = \gamma mc^2 - mc^2$$

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

γ is the relativistic factor

E$_k$: kinetic energy of the body (in the considered reference frame);

v : body speed (in the considered reference frame);

m : its mass at rest (in *its* reference frame);

c : speed of light in vacuum (in *any* inertial reference frame);

γmc^2 : *total energy* of the body (in the considered reference frame);

mc^2 *: is* the energy at rest (90 petajoules per kilogram) expressed in conventional units.

The theory of relativity states that the kinetic energy of an object (having non-zero "rest" mass) tends to infinity when its velocity approaches the velocity of light, and that it is therefore impossible to accelerate an object to this velocity.

KINETIC ENERGY THEOREM

This theorem, valid only within Newtonian mechanics, makes it possible to link the kinetic energy of a system to the work done by this system.

States:

In a Galilean reference frame, for a point body of constant mass *m* traversing a road connecting a point A to a point B, the change in kinetic energy is equal to the sum of the work *W* of the external and internal forces that are exerted on the considered solid:

$$E_{kAB} = E_{kB} - E_{kA} = \sum W_{fEXT/INT}^{AB}$$

where E $_{kA}$ and E $_{kB}$ are the kinetic energy of the solid at points A and B, respectively.

MECHANICAL POTENTIAL ENERGY

Mechanical potential energy is the energy that is changed by a body when it moves while being subjected to a conservative force.

It is expressed in joules (meaning - newtons multiplied by meters).

This potential energy, defined up to an arbitrary constant, depends only on the position of the body in space.

This energy is called *potential* because it can be stored by a body and then *transformed*, for example, into kinetic energy when the body is set in motion.

Specifically, the change in potential energy of a body when it moves between two points is the opposite of the work done by the force it is exposed to (between those two points).

Thus, the work of a conservative force verifies the relation: $\delta W_F = -dE_p$

A simple example is that of a terrestrial body held upwards (and therefore possessing gravitational potential energy due to its height) which, once released, converts this potential energy into kinetic energy when its velocity increases during its fall.

MECHANICAL POTENTIAL ENERGY – GENERAL VIEW

Every conservative force gives rise to potential energy, thus it can be distinguished:

- Gravitational potential energy,
- Elastic potential energy,
- Electrostatic potential energy,
- Magnetic potential energy,
- Conduction of inertial potential energy (in some simple situations).

Ep= m·g·h

Gravitational potential energy

Gravitational potential energy is the energy that a body possesses due to its position in a gravitational field.

As for all energy, its unit in the international system is the joule.

This potential energy is noted as "E_{pp}" or "U_0"

It is defined by the relation: $\delta W_p = \vec{P}.d\vec{z} = -\delta E_{pp}$

p being the weight of the object itself (the force acting on it due to its mass and position in a gravitational field)

Current approximation:

Most often, on Earth, gravity is considered to be of constant value, orientated downward (towards the center of the Earth) and of a value of

g= 9.81 m/s^2.

In this case, choosing sea level as the origin of the potentials, then this energy is equal to: E_{pp} = m·g·h (m is expressed in kg and h (altitude) is expressed in m)

But for a given problem, generally only potential differences are considered.

Between the elevation points z_0 and z_1, the potential energy difference is: $\Delta Epp=mg\ (z_1-z_0)$

(energy received during the motion from the altitude point z_0 to the altitude point z_1).

Depending on the problem, we can therefore establish an arbitrary origin of the potentials, especially since it poses no particular problem to have a negative potential energy. For example, if we study the fall of an object on the floor of a laboratory, we fix the origin of the potentials at the level of this floor, regardless of the actual altitude of the laboratory.

General case

In any problem involving gravity, it is important that the calculation by applying the fundamental principle of dynamics is consistent with the conservation of energy.

Here, it implies that the expression used for gravitational potential energy is consistent with that used for gravity itself. The weight should always come from the Epp.

If we use the following formula (approximation at 0° latitude) to evaluate gravity: g= 9.780318.(1-3.15.10^{-7} h)

then Epp, expressed as a function of altitude, becomes:

Epp=m.9.780318.(h- 1.57.10^{-7}.h^2)

For an object far from the surface of the earth, the gravitational potential energy (no longer gravity) is rather 1/r (the inverse of the distance **), since gravity itself is 1/r^2.**

ELASTIC POTENTIAL ENERGY

In physics, **elastic potential energy** is the potential energy stored in an elastic body when it is compressed or stretched from its natural position.

When the force compressing or stretching the spring stops, the body naturally tends to return to its natural position and thus converts its potential energy into kinetic energy.

The elastic nature of an object is remarkable for its ability to spring back or regain its shape after deformation.

The elastic potential energy, noted as Epe and expressed in **joules**, depends on *x* (the lengthening or shortening of the spring) and the elastic constant or stiffness *k* of the spring, according to the relationship: $E_{pe} = \frac{1}{2} kx^2$

If it is considered a landmark with $(0.\vec{i})$ the representation of the position of the end of the spring at rest and directed along the spring axis.

Then the elastic force has the following expression: $\vec{F} = -k.x.\vec{i}$

POWER

In physics, power is the amount of energy per unit time supplied by one system to another.

Power therefore corresponds to a flow of energy: two systems of different powers can provide the same work (same energy), but the more powerful system will be the fastest.

POWER is generally expressed in Watts, in Joules/second or in kg.m^2.s^{-3}

In some cases, high power (high energy for a short period of time) is required at startup, so only powerful systems can operate the device.

Power is always equal to the product of an effort quantity (force, torque, pressure, tension, etc.) by a flow quantity (velocity, angular velocity, flow rate, current intensity, etc.).

MECHANICAL POWER

The mechanical power of a force is the energy that can be gained or lost with that force in a given time.

The SI unit of power is the watt (symbol: W), which corresponds to one joule delivered per second.

Horsepower is still used in heat engines: 1hp (horsepower)= about 736 W

AVERAGE POWER P_m is the energy E provided by a phenomenon divided by the duration τ of this phenomenon: $P_m = \frac{E}{t}$

INSTANTANEOUS POWER is the derivative of the energy supplied with respect to time: $P_m = \frac{dE}{dt}$

THE POWER OF A FORCE

If the point of application of a force (in N) is moving with the instantaneous velocity (in m/s), then the instantaneous power is in value (in watts)

It can be easily found the result by deriving the work of a force: $P = \vec{F}.\vec{v}$

KINETIC POWER THEOREM

In a Galilean reference frame, the strength of the forces acting on the point M is equal to the time derivative of the kinetic energy.

$$P = \frac{dE_c}{dt}$$

STATICS

Statics studies the forces in the following situation:
Reduction or composition of forces, which consists in creating a system of forces equivalent to the initial system of forces.

Equilibrium of systems of forces: i.e. establishing the conditions that must be met for the given system of forces to be in equilibrium.
A force system consists of a set of forces that may be concurrent, arbitrary, or parallel.

Two systems of forces are equivalent if they produce the same mechanical effect on the body to which they are applied.
A system of forces is equal to zero if under their action the body does not change its mechanical state of rest or motion.

Statics can address the following directions:

- Statics of the material point
- Force systems and their reduction
- Centers of gravity
- Statics of the rigid body
- Statics of system of material points and systems of rigid bodies
- Technical applications of statics

VECTOR CALCULUS

Vectors are oriented physical quantities, completely determined by:

- **Modulus** (magnitude, value)
- **Application point** (origin)
- **Direction**
- **Sense**

Examples : force, velocity, acceleration, moment of a force.

The elements of a vector are:

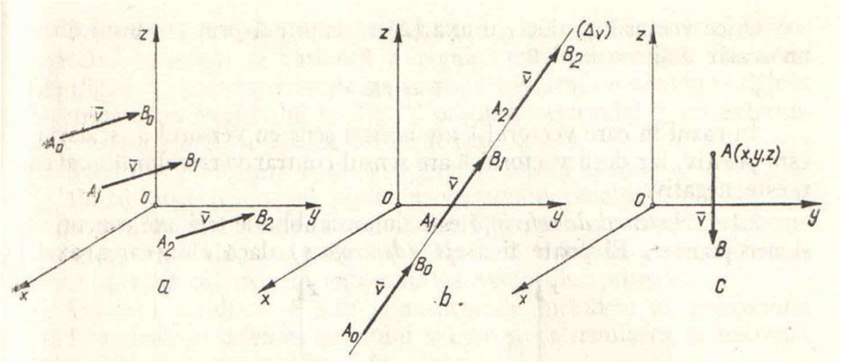
Origin A (Application Point)

Direction (support or line of application)

Sense (A to B)

Mode or numerical value | v| which represents the length of segment AB at the scale chosen for the graphic representation.

VECTOR CLASSIFICATION



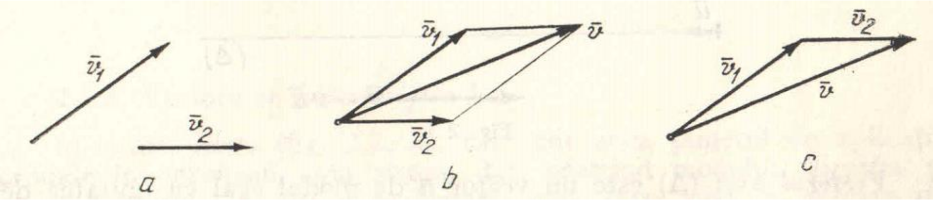
a) **free vectors**: the point of application can be anywhere in the given system, preserving the modulus, direction and sense. *For example*, the velocity and acceleration of a body in translational motion.

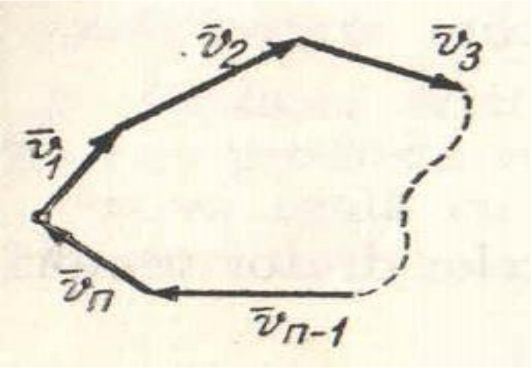
b) **sliding vectors**: the point at which the application can be moved anywhere on its support, preserving the modulus, direction and sense. *For example*, angular velocity, angular acceleration, force in the case of a non-deformable rigid solid.

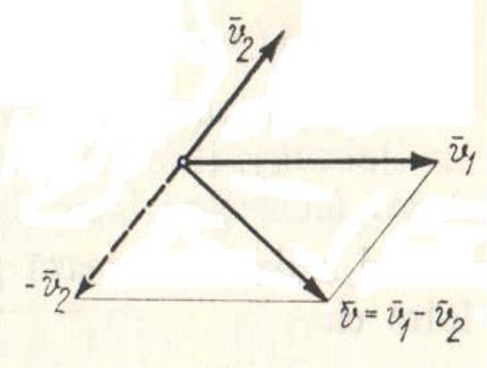
c) **related vectors** whose origin is well defined at a certain point, preserving the magnitude, direction and sense. *For example*, the force in the case of elastic bodies, the moment of force related to a point, the velocity and acceleration of a moving body are arbitrary.

The sum of two free vectors

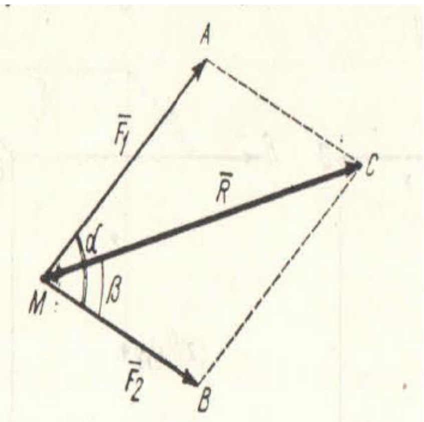
v1 and v2



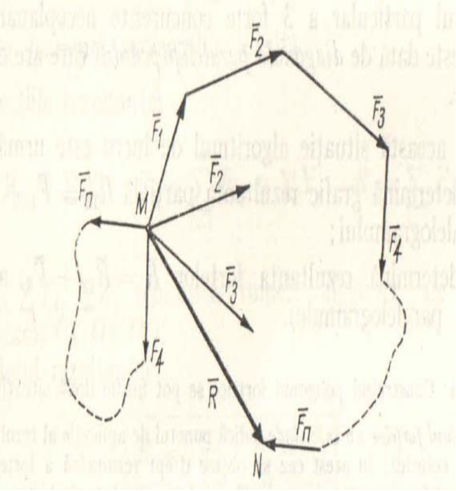




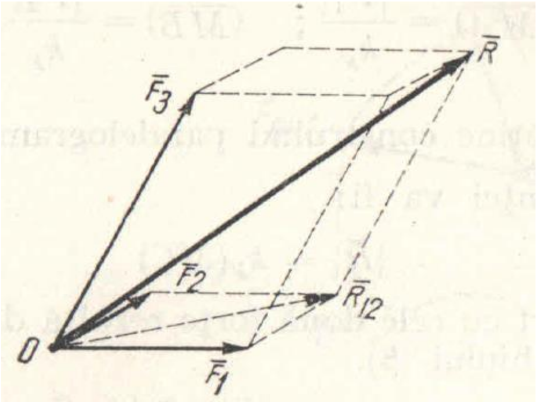
Composition of two concurrent forces by the graphical method



Composing concurrent forces by the graphical method



Polygon rule: if the forces are concurrent, the resultant R is the diagonal of a parallelepiped.



The algorithm for this situation is as follows:

1. Graphical determination of the partial resultant: $\vec{R}12 = \vec{F}1 + \vec{F}2$

2. Determine the resultant of the forces: $\vec{R} = \vec{R}_{12} + \vec{F}_3$

In both situations, the parallelogram rule applies.

Statics: Composition of concurrent forces by the analytical method

We use the projection theorem: each force is projected onto the axes Ox, Oy, and Oz.

The case of the n concurrent forces that form the angles αi, βi , γi

These angles are formed by the support forces and the coordinate axes.

For strengths: $\vec{R} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ... + \vec{F}_n = \sum_{i=1}^{n} \vec{F}_i$

$$F_{1x} = pr_{Ox}\vec{F}_1 = \left|\vec{F}_1\right|.\cos\alpha_1; \quad F_{1y} = pr_{Oy}\vec{F}_1 = \left|\vec{F}_1\right|.\cos\beta_1; F_{1z} = pr_{Oz}\vec{F}_1 = \left|\vec{F}_1\right|.\cos\gamma_1;$$

$$F_{2x} = pr_{Ox}\vec{F}_2 = \left|\vec{F}_2\right|.\cos\alpha_2; \quad F_{2y} = pr_{Oy}\vec{F}_2 = \left|\vec{F}_2\right|.\cos\beta_2; F_{2z} = pr_{Oz}\vec{F}_2 = \left|\vec{F}_2\right|.\cos\gamma_2;$$

$$F_{3x} = pr_{Ox}\vec{F}_3 = \left|\vec{F}_3\right|.\cos\alpha_3; \quad F_{3y} = pr_{Oy}\vec{F}_3 = \left|\vec{F}_3\right|.\cos\beta_3; F_{3z} = pr_{Oz}\vec{F}_3 = \left|\vec{F}_3\right|.\cos\gamma_3;$$

For the resultant force:
$$R_x = pr_{Ox}\vec{R} = \left|\vec{R}\right|.\cos\alpha$$
$$R_y = pr_{Oy}\vec{R} = \left|\vec{R}\right|.\cos\beta$$
$$R_z = pr_{Oz}\vec{R} = \left|\vec{R}\right|.\cos\gamma$$

The resulting force projections are: where the sums mean algebraic sums of the force projections

on the axes Ox, Oy, Oz.
$$R_x = \sum_{i=1}^{n} F_{ix} = \sum X_i$$
$$R_y = \sum_{i=1}^{n} F_{iy} = \sum Y_i$$
$$R_z = \sum_{i=1}^{n} F_{iz} = \sum Z_i$$

The leading cosines of the resultant force support are:

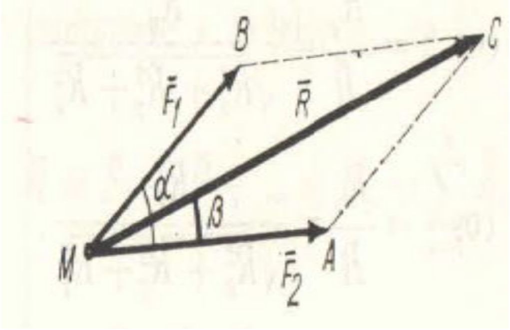
$$\cos\alpha = \frac{R_x}{R} = \frac{R_x}{\sqrt{R_x^2 + R_y^2 + R_z^2}}$$

$$\cos\beta = \frac{R_y}{R} = \frac{R_y}{\sqrt{R_x^2 + R_y^2 + R_z^2}}$$

$$\cos\gamma = \frac{R_z}{R} = \frac{R_z}{\sqrt{R_x^2 + R_y^2 + R_z^2}}$$

The modulus of the resultant force: $\left|\vec{R}\right| = \sqrt{R_1^2 + R_2^2 + R_3^2}$

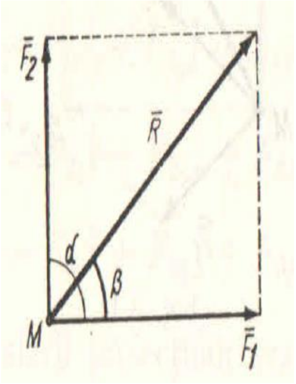
Two concurrent coplanar forces oriented in arbitrary directions:



Two concurrent coplanar forces perpendicular to each other:

$$\left|\vec{R}\right| = \sqrt{F_1^{\,2} + F_2^{\,2} + F_1F_2\cos\left(\vec{F}_1,\vec{F}_2\right)}$$

$$\frac{\left|\vec{F}_1\right|}{\sin(\alpha-\beta)} = \frac{\left|\vec{F}_2\right|}{\sin(\beta)} = \frac{\left|\vec{F}_3\right|}{\sin(\alpha)}$$



$$\left|\vec{R}\right| = \sqrt{F_1^{\,2} + F_2^{\,2}}$$

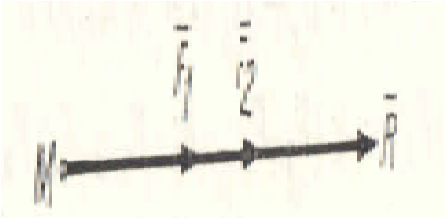
$$tg\beta = \frac{F_2}{F_1}$$

COMPOSITION OF CONCURRENT FORCES BY ANALYTICAL METHOD

Two concurrent forces having the same direction and sense

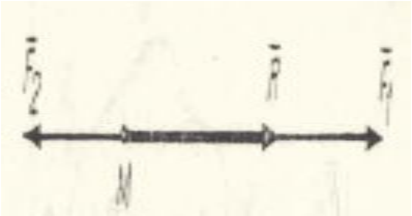
| R | = | F1+F2 |

bronze β=0 (β=0)



Two concurrent forces having the same direction but different senses

| R | = | F1-F2 |

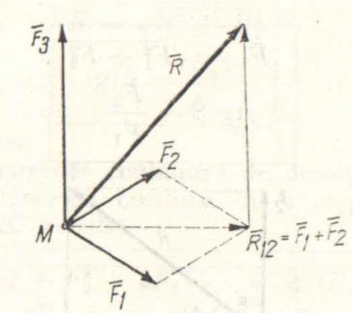


Three concurrent forces having arbitrary directions in space

The modulus of the resultant force is obtained by squaring the vector force composition equation.

$$\vec{R} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3$$

$$\left|\vec{R}\right| = \sqrt{F_1^2 + F_2^2 + F_3^2 + 2F_1F_2\cos\left(\vec{F}_1, \vec{F}_2\right) + 2F_1F_3\cos\left(\vec{F}_1, \vec{F}_3\right) + 2F_2F_3\cos\left(\vec{F}_2, \vec{F}_3\right)}$$



$$\cos\alpha_1 = \frac{F_1 + F_2\cos\left(\vec{F}_1, \vec{F}_2\right) + F_3\cos\left(\vec{F}_1, \vec{F}_3\right)}{R}$$

$$\cos\alpha_2 = \frac{F_1\cos\left(\vec{F}_1, \vec{F}_2\right) + F_2 + F_3\cos\left(\vec{F}_2, \vec{F}_3\right)}{R}$$

$$\cos\alpha_3 = \frac{F_1\cos\left(\vec{F}_1, \vec{F}_3\right) + F_2\cos\left(\vec{F}_2, \vec{F}_3\right) + F_3}{R}$$

$\alpha 1$, $\alpha 2$, $\alpha 3$ are the angles formed by the resultant force R with the vectors F1, F2, F3.

COMPOSITION OF CONCURRENT FORCES BY ANALYTICAL METHOD

THREE CONCURRENT FORCES HAVE ANY DIRECTIONS IN SPACE

If the forces F1, F2, F3 are defined using their projections on the axes Ox, Oy and Oz, the resultant force of the three composite forces is:

$$\vec{F}_1 = F_{1x} \cdot \vec{i} + F_{1y} \cdot \vec{j} + F_{1z} \cdot \vec{k}$$
$$\vec{F}_2 = F_{2x} \cdot \vec{i} + F_{2y} \cdot \vec{j} + F_{2z} \cdot \vec{k}$$
$$\vec{F}_3 = F_{3x} \cdot \vec{i} + F_{3y} \cdot \vec{j} + F_{3z} \cdot \vec{k}$$

The size of the vector

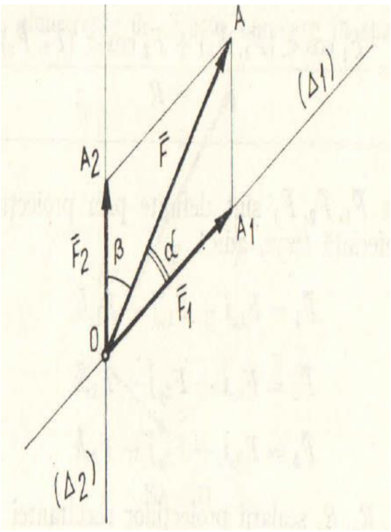
$$R_x = F_{1x} + F_{2x} + F_{3x}$$
$$R_y = F_{1y} + F_{2y} + F_{3y}$$
$$R_z = F_{1z} + F_{2z} + F_{3z}$$

Scalar quantity

COMPOSITION OF A FORCE FOLLOWING GIVEN CONCURRENT DIRECTIONS

DECOMPOSITION OF A FORCE FOLLOWING 2 GIVEN CONCURRENT DIRECTIONS

Graphical method



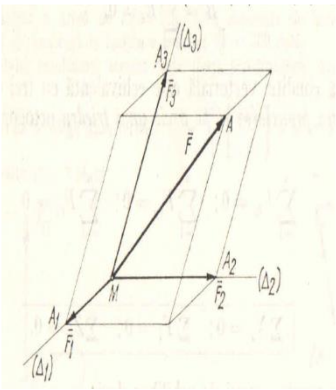
Analytical method:

$$\frac{F_1}{\sin\beta} = \frac{F_2}{\sin\alpha} = \frac{F}{\sin(\alpha+\beta)}$$
$$F_1 = F \cdot \frac{\sin\beta}{\sin(\alpha+\beta)}$$
$$F_2 = F \cdot \frac{\sin\alpha}{\sin(\alpha+\beta)}$$
$$F_1 = F\cos\alpha = F\sin\beta$$
$$F_2 = F\sin\alpha = F\cos\alpha\beta$$

when Δ_1 is perpendicular to Δ_2 :

DECOMPOSITION OF A FORCE FOLLOWING 3 NON-COPLANAR INSTRUCTIONS CONCURRENT

Graphical method: projection theorem



Analytical method:

$$\vec{F}_1 = k_F\left(\vec{OA}_1\right)$$

is deduced with $\vec{F}_2 = k_F\left(\vec{OA}_2\right)$

$$\vec{F}_3 = k_F\left(\vec{OA}_3\right)$$

EQUUILIBRE OF FREE MATERIAL POINT

If we consider a free material point that is at rest with respect to an inertial reference frame, the question that arises is to find the necessary and sufficient condition for the material point to continue to remain at rest after undergoing a system of forces - that is to remain in balance.

According to the principle of the parallelogram of forces, the system of applied forces is equivalent to a resultant force: $R = \sum_{i=1}^{n} F_i$

$$R = \sum_{i=1}^{n} F_i = 0$$

ou

$$\sum_{i=1}^{n} F_{ix} = 0; \sum_{i=1}^{n} F_{iy} = 0; \sum_{i=1}^{n} F_{iz} = 0$$

ou

$$\sum_{i=1}^{n} X_i = 0; \sum_{i=1}^{n} Y_i = 0; \sum_{i=1}^{n} Z_i = 0$$

According to the principle of inertia of the material point: the material point maintains its state of rest if no force is exerted on it.

To fulfill the translational equilibrium condition, it is necessary and sufficient that the resultant of the system of competing forces is zero.

LEVERS

Definition: A lever is a rigid beam that moves about a fixed point called a fulcrum.

Two forces act on a lever :

- **a driving force F** , which sets the lever in motion
- **a resisting force R** , which must be overcome

In the case of the bone lever, the fulcrum S is represented by the biomechanical axis of movement, the fulcrum on the ground or any device (in the gym).

The resistance force R is represented by the weight of the body or the moving segment and the active force F is the muscle that performs the movement.

The lever is based on the balance of the moments of the two forces:
active and resistance passive.

$$M_F = M_R ; M_F = F.b_r ; M_R = R.b_R$$

$$F.b_r = R.b_R \Rightarrow \frac{F}{R} = \frac{b_r}{b_R}$$

Or:

▸**MF** - moment of active force;

▸**MR -** moment of resistance force;

▸**bF** – active force arm;

▸**bR** - the arm of the resisting force.

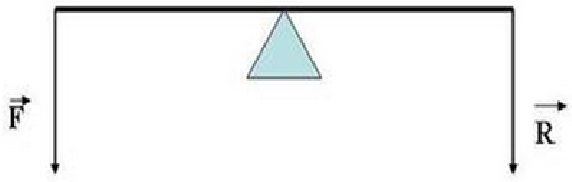
Levers are characterized by three main points:

▸- The point of application of force F

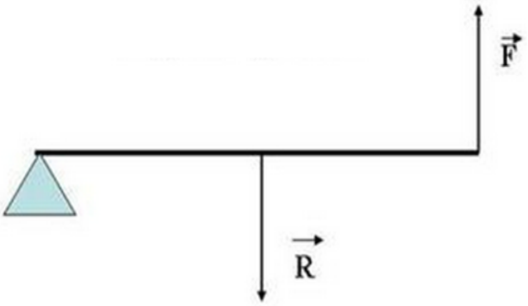
▸- The point of application of resistance R

▸- The point of application S of the resultant forces, called the fulcrum of the lever around which the forces F and R impart a rotational motion to the lever.

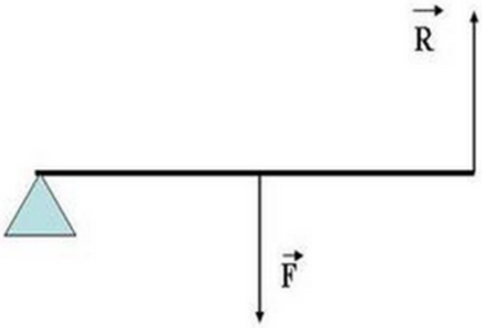
The classification of levers is done according to three points of application F, R and S



<u>THE LEVER OF THE FIRST DEGREE</u> has the support point located between the points of application of the two forces.



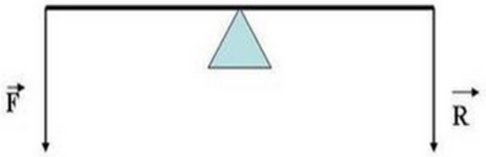
<u>THE LEVER OF THE SECOND DEGREE</u> has the fulcrum at one end and the point of application of the active force at the other end.



<u>THE THIRD DEGREE LEVER</u> has the fulcrum located at one end and the point of application of the resisting force at the other end.

EXAMPLES OF LEVERS

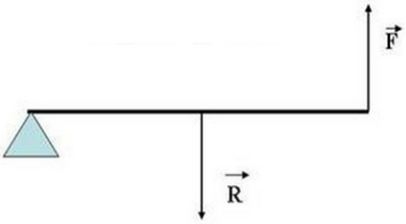
First degree lever has its fulcrum located between the points of application of the two forces



Examples of first degree levers: scale, seesaw, scissors, tongs, crowbar, tongs.

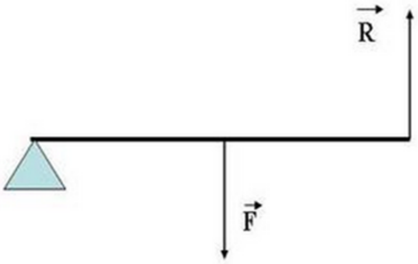
Second degree lever has the fulcrum at one end and the point of application of the active force at the other end.

Examples of second degree levers: wheelbarrow, nutcracker, brake pedal, punch, oar, etc.

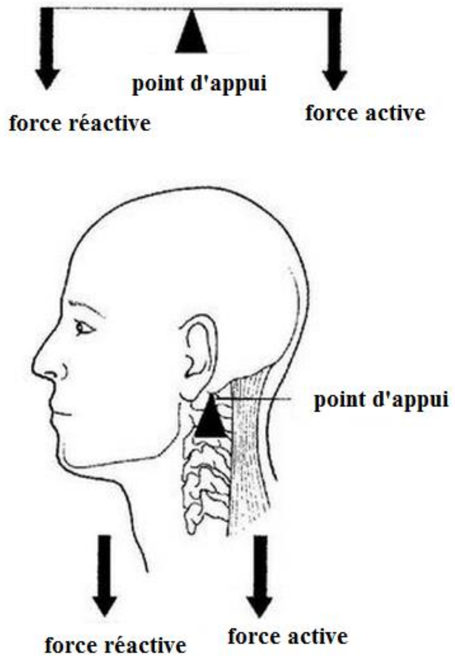


Third degree lever has the fulcrum located at one end and the point of application of the resisting force at the other end.

Examples of third degree levers: stapler, rake, fishing rod, etc.



LEVERS IN THE HUMAN BODY



- **First class levers are balancing levers because they achieve static balance.**

The reactive force is the weight of the body or the moving segment and

The active force is the insertion on the skeletal segment of the muscle that performs the movement.
According to (A. Neagu, M. Neagu, Biophysics Course for the Faculty of Dental Medicine, Ed. Eurobit, 2007)

IDENTIFICATION OF THE FIRST CLASS LEVERS IN THE HUMAN BODY :

THE TRUNK IS BALANCED ON THE LEGS like a **first class lever** ;

THE HEAD IS BALANCED ON THE SPINE. The fulcrum is the atlas vertebra, the resistance is the weight of the head, which tends to fall forward, and the active force is developed by the neck muscles which prevent the head from falling forward.

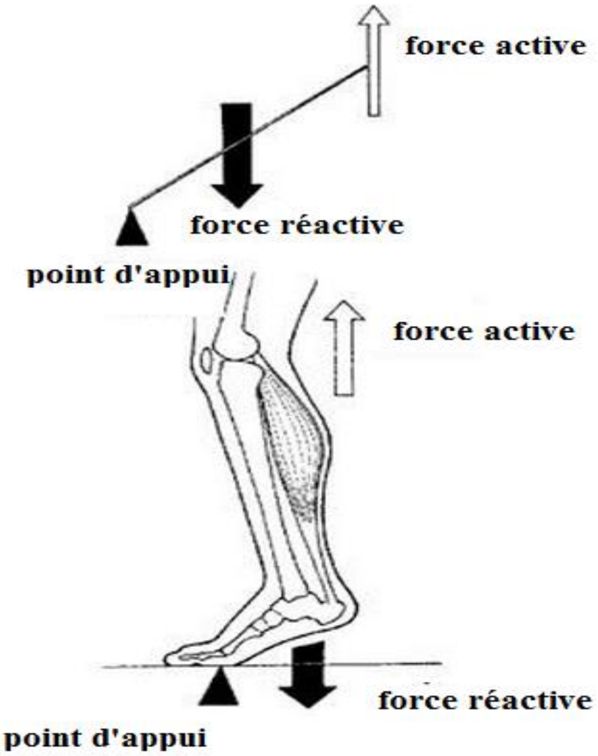
- **THE FOREARM IN EXTENSION** acts as a lever of the first degree: during the flexion and extension of the arms in the "reverse support in tension" the extensor muscles have the role of agonists in both the extension and flexion movements of the arms. In this position, the flexion of the arms is achieved by the weight and graded by the extensor muscles (triceps); the latter also perform elbow extension.
- **WHEN THE FEET ARE FIXED TO THE FLOOR**

(while running, walking, kicking when jumping, falling from a height **), the leg segment is also a first class lever with the fulcrum in the center.**

Second class levers are the levers of force because they serve to multiply the force.

These levers are usually wedge-shaped.

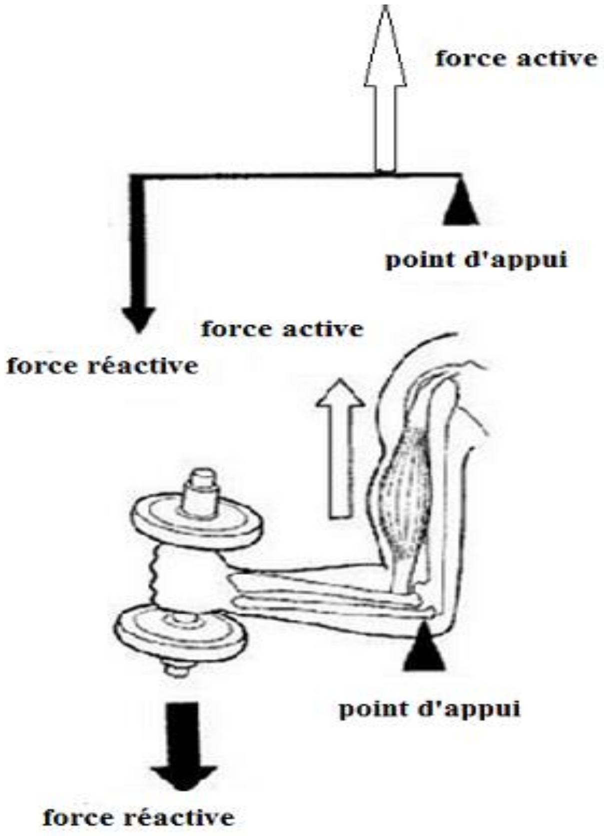
IDENTIFICATION OF THE SECOND DEGREE LEVERS IN THE HUMAN BODY



According to (A. Neagu, M. Neagu, Biophysics Course for the Faculty of Dental Medicine, Ed. Eurobit, 2007)

- **Incisor teeth**
- **Canine teeth**
- **The leg** having as its resistance the weight of the body transmitted by the tibia. The weight of the body is applied to the tibio-tarsal joints, so that the force will be given by the muscles inserted on the heel by the Achilles tendon. The point of support when standing on the tip of the feet is at the end of the metatarsals that are in contact with the ground.
- **Upper limb segment** while doing push-ups.
- **third class levers** are levers for motion.

With the help of a superior force, they overcome an insignificant force, but greatly move the point of application of the resisting force.



- **This type of lever is most commonly found in the human body.**
- In this type of lever, the point of application of the active force - the place of insertion of the muscle - is placed between the fulcrum that is the joint and the point of application of the resisting force.

According to (A. Neagu, M. Neagu, Biophysics Course for the Faculty of Dental Medicine, Ed. Eurobit, 2007)

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IDENTIFICATION OF THIRD CLASS LEVERS IN THE HUMAN BODY:

FOREARM FLEXION is a third-degree lever when raised by contracting the flexor muscles. Biceps contraction produces a force whose point of application is located on the forearm. In this case, the arm of the active force is about eight times smaller than the arm of the resisting force, from which it follows that the arm of the active force must be eight times greater than the arm of the resisting force.

RIBS DURING BREATHING (inspiration and exhalation). The costovertebral joint is the fulcrum, the muscle insertion areas on the body of the rib are the point of application of the active force, and the face of the rib is the resisting force.

THE FOOT IN THE GAME OF SOCCER: when taking the volleyball, the foot is not fixed on the ground so that the point of application of the active force is in the middle, and the resistance consists of a combination of forces (the weight of the ball), leg weight, etc.).

For example: if we add the weight of the foot, the weight of the foot, the weight of the ball, the contraction force of the leg extensor muscles on the thigh and the acceleration values resulting from the movement. of the forward foot, it follows that a soccer ball can be kicked with a force of about 2 kN even by an untrained person.

HAND when grasping objects like pincers.

BALANCE

A BALANCE, from the Latin *bis* (twice) and *lanx* (podis), is a measuring instrument used to assess masses by comparison with "weights" in common language, or "marked masses" whose masses are known.

The scale has been around since ancient times. The scale requiring the use of weights, forced to adjust the weighing with the greatest care. Scales did not become true precision instruments until the 19th century.

In the 17th century , Roberval's invention revolutionized weighing with the idea of placing the plates above the beam and not below.

A "good" balance must be fair, sensible and faithful.

BALANCE TYPES

In the 18th century , the observations and gains in sensitivity due to Lavoisier were conducive to effective use in laboratories.

The Roberval balance was perfected by Béranger who reduced lateral forces and friction by replacing the force rods with small secondary beams.

In the 20th century, **the "Roberval" and "Béranger" scales were on all shop counters** when, in the second half of the 20th century, the "automatic scale" with a graduated, circular or shaped dial appeared, by the position of a moving marker without having to manually move the weight.

Electronics are at the origin of a technological change with scales equipped with screens and printers that provide desirable data such as, in trade, the price of the weighed quantity.

HAND BALANCE

It is used to weigh small amounts of substance, usually 0.05g-100-200g.

Several limitations are known, such as 0.25; 0.5;1;2;5;10;20 g – with decreasing sensitivity.

The hand scale consists of a metal lever suspended with an arrow pointing upwards, with two equal arms swinging around a fulcrum with a ring-like termination.

Hand balance can be simple or sliding .

With simple hand scales, weighing is done by balancing the weight of the substance on one of the pans with appropriate weights placed on the opposite pan.

On slider hand scales, one of the arms (usually the left) is graduated, and the slider sliding along the lever indicates the weight being weighed (the weight is placed on the pan, usually the non-weighing arm).

Sometimes weights can be gradually added to the left arm.

This operation is not particularly recommended for weighing highly active substances.

ELECTRONIC BALANCE

The principle of operation of these balances is based on the variations in the electrical characteristics of certain materials when they are subjected to mechanical compression.

These electrical variations are measured and sent to a dial that gives an indication of the mass of the unknown charge that compressed the material.

Depending on the smallest mass they can measure, electronic scales are classified according to the smallest division and typical capacity:

- Analytical balance:
- Ultramicroanalytical (0.1 µg / 3g)
- Microanalytical (0.001 mg / 3 g)
- Semi-microanalytical (0.01 mg / 30 g)
- Macroanalytical (0.1 mg / 160 g)
- Precision balance (1 mg / 160 g - 60 kg)

THE PHARMACEUTICAL BALANCE is called **a column scale,** being the most used in the pharmacy.

It is used to weigh from 10 to 1000 g or from 500 g to 5 cg with centigram sensitivity.

The scale consists of a metal column, mounted vertically on a box or support, usually covered with a marble plate with 1-3 drawers.

The top of the column rests on a knife, a horizontal lever with equal arms that are suspended from the knife, with two trays.

The balance of the balance is indicated by the indicator positioned in the middle of the lever that oscillates with it in front of a graduated dial.

The scale must be balanced before each weighing.

Pharmaceutical balances have an arm adjustment screw at each end.

ANALYTICAL BALANCE SHEETS

They are also called **precision scales** .

They are used for weighing with high sensitivity.

Errors can be tens of milligrams.

This type of balance is used in laboratories for quantitative analytical determinations when the Pharmacopoeia uses the expression "accurately weighed".

Weighing results are expressed to four decimal places (the Pharmacopoeia allows an error of ±0.0002 g).

Analytical balances XPE-a Metler-Toledo intelligent balance

http://fr.mt.com/fr/fr/home/products/Laboratory_Weighing_Solutions/Analytical.html?smartRedirectEvent=true

▸**XPE analytical balances offer the highest performance in analytical weighing and meet the most stringent requirements for safety, efficiency and compliance. Due to their low repeatability, XPE analytical balances give you the benefit of the lowest minimum weight.** Quality management features such as innovative StatusLight™ technology and patented StaticDetect™ functionality eliminate weighing worries and give you complete confidence in your results. Featuring a wide range of accessories and multiple connectivity options, XPE scales grow with your needs. You'll enjoy a wealth of weighing possibilities for years to come. Engineered, engineered and manufactured in Switzerland for unmatched quality and reliability. Get smart weighing features: • New color display with StatusLight warning function • Patented StaticDetect functionality • New electrostatic charge elimination technology • TestManager™ that makes routine testing easier • Revised and revised SmartGrid weighing tray • LabX® software for personalized on-screen work instructions

The world's most sensitive scale: weighing to the yoctogram

1 yg (yoctogram) = 10^{-24} g = 10^{-27} kg

http://www.techniques-ingenieur.fr/actualite/high-tech-thematique_193/la-balance-la-plus-sensible-au-monde-peser-au-yoctogramme-pres-article_71917/?utm_source=ABO&utm_medium=alerte&utm_campaign =tiThematic_6345

Catalan researchers have managed to measure the smallest units of mass, to the nearest yoctogram, using a balance whose principle is centered around the vibration of short carbon nanotubes.

A billionth of a billionth of a millionth of a gram: Catalan researchers at the Catalan Institute of Nanotechnology in Barcelona have succeeded in developing the world's most sensitive balance, sensitive enough to measure the smallest units of mass... to the nearest yoctogram , or 10 to the power minus 27 kilograms Weighing an atom down to its last proton could almost become child's play!

The most sensitive balances are currently capable of measuring masses up to a hundred yoctograms and rely on the vibration of nanotubes_when a table rests on them. Indeed, it is enough to calculate the vibrational frequency of these nanotubes to deduce the mass of the particle or molecule resting on them.

Adrian Bachtold and his colleagues at the Catalan Institute of Nanotechnology used shorter nanotubes to measure even smaller masses. The resolution is improved, at low temperature. The equipment was placed in near-vacuum conditions to minimize interference with other atoms, taking great care to remove the last stray atoms by increasing the temperature of the nanotubes, thereby severing any potential bonds with other atoms. **The Catalans were then able to weigh an atom of xenon, to the nearest yoctogram, and were therefore able to measure the smallest proton (i.e. 1.7 yoctograms**).

▶Such a balance could help distinguish between different elements in a sample, some differing by only a few protons. It could also help identify differences in weight on the order of a proton at the molecular level, which could be a marker of disease, potentially facilitating certain diagnoses.

Precision technical balances are designed for use in weighing processes in laboratories, research, medicine, pharmacy, education, the food industry, electronics and the general public interest.
economical technical scales with separate weighing platforms – WLCK

Examples:

WLC 6/F1- capacity: 6 Kg, Accuracy 0.1 g
WLC 12/F1 - capacity: 12 Kg, Accuracy 0.2g
WLC 30/F1 - capacity: 30 Kg, Accuracy 0.5g
WLC 60/C21 - capacity: 60 Kg, Accuracy 1g
WLC 120/C2 - capacity: 120 Kg, Accuracy 2g


www.multilab.ro/balante/balanta_farmacie.html

OSCILLATION THEORY

INTRODUCTION

OSCILLATIONS or oscillatory movements represents the movements that repeat periodically or quasi-periodically in time.

Depending on their physical nature, mechanical, electromagnetic, etc. oscillations are distinguished.

Oscillations can be classified according to several criteria. Thus, periodic oscillations are distinguished if all the values of the physical quantities characteristic of the oscillation process are repeated at regular time intervals which are minimum time intervals T.

This value T is the period of the oscillations and represents the duration of a complete oscillation.

The frequency of oscillations is the number of complete oscillations performed per unit of time:

$$\nu = \frac{1}{T}$$

The time dependence of any physical quantity A that characterizes a periodic oscillation has the following form: A(t) = A0 + X(t)

where: A0 = constant and X(t) is a periodic function of time:

X(t+T) = X(t)

If only part of the characteristic physical quantities are of this type, then the oscillations are quasi-periodic.

CLASSIFICATION OF OSCILLATIONS

DEPENDING ON THE VARIATION OVER TIME OF THE CHARACTERISTIC QUANTITIES, it can be distinguished:

- PERIODIC OSCILLATIONS in which all the physical quantities characteristic of the oscillation process are repeated at regular time intervals.

The minimum time interval is the oscillation period T and is the period of one complete oscillation.

Frequency (ν) is the number of complete oscillations performed per unit time.

- Quasi-periodic OSCILLATIONS for which only part of the characteristic physical quantities are quasi-periodic.

Depending on the TYPE OF EXTERNAL FORCES THAT DETERMINE OSCILLATIONS, it can be distinguished:

- FREE OSCILLATIONS (occurring in the absence of external frictional or motion-maintaining forces)
- DAMPED OSCILLATIONS (frictional forces are present)
- FORCED OSCILLATIONS (under the action of external forces maintaining the movement)

DEPENDING ON THE TYPE OF DIFFERENTIAL EQUATIONS THAT DETERMINE THEM, the oscillations are classified as follows:

- LINEAR OSCILLATIONS if the corresponding equations of motion are linear differential equations.
- NONLINEAR OSCILLATIONS otherwise.

HARMONIC OSCILLATORY MOTION

The simplest oscillatory motion is harmonic oscillatory motion which is motion that occurs under the action of an elastic force.

The elastic force is a force whose support always passes through a fixed point 0 (the center of motion) whose magnitude is proportional to the distance between 0 and the point of application of the force and whose direction is opposite to the displacement.

The expression for the elastic force is: $\vec{F}_e = -k.\vec{r}$

where k is a proportionality constant called elasticity constant or elasticity coefficient.

After that, we only consider one-dimensional harmonic oscillatory motion on the Ox axis.

In this case, the elastic force has the form Fe = - kx, where the distance

x = x (t) with respect to the center O is called elongation.

The problem is to study the motion of a material point on which an elastic force is exerted. The system thus formed is called **a linear harmonic oscillator** .

The characteristic equation for this system is:

$$\boxed{m \cdot \ddot{x} + kx = 0} \quad \text{or} \quad \boxed{m \cdot \frac{d^2x}{dt^2} + kx = 0} \qquad (1)$$

If we divide equation (1) by the mass ma of the oscillator and if we introduce the notation for **self-pulsation** $\omega = \sqrt{\frac{k}{m}}$

then equation (1) becomes: $\ddot{x} + \omega^2 x = 0\,(2)$

or $\frac{d^2x}{dt^2} + \omega^2 x = 0\,(3)$

This equation is called **the differential equation of harmonic linear oscillatory motion.**

Differential equation of harmonic linear oscillatory motion $\boxed{\frac{d^2x}{dt^2} + \omega^2 x = 0}$

The solution of this equation is the law of oscillation and can be written in the following form:

$$\boxed{x(t) = A\cos(\omega t + \varphi)}$$

The quantities A and φ are constant and depend on the initial conditions of the motion.

The argument of the cos function in the law of motion is – that is, the magnitude: $\psi(t) = \omega t + \varphi$ it is called the movement phase and φ it is called the initial phase.

Initially t = 0 the phase becomes $\psi(0) = \varphi$

and therefore represents the reference phase which is called the initial phase of the movement.

if $\omega t + \varphi = 2n\pi$ then, $\cos(\omega t + \varphi) = 1$

so the maximum elongation x is A which is the range of motion.

Simple harmonic oscillatory motion is periodic motion.

The elongation x(t) is periodic in time and has the same value as time t increases by one period, as follows:

$$x = A\cos(\omega t + \varphi) = A\cos[\omega(t + T) + \varphi]$$

The frequency of oscillation is: $\omega t = 2\pi \ ou \ \omega = \dfrac{2\pi}{T} = 2\pi\nu$

The velocity of the material point in harmonic oscillatory motion is: $v = \dot{x} = -\omega A \sin(\omega t + \varphi)$

The acceleration is: $a = \ddot{x} = -\omega^2 A\cos(\omega t + \varphi) = -\omega^2 x$

Therefore, in a harmonic oscillatory motion, the acceleration is proportional and opposite to the elongation.

The law of harmonic and linear oscillatory motion can be put into one of the following forms which are equivalent:

$x = A \cdot \cos(\omega \cdot t + \varphi)$

$x = a \cdot \sin \omega t + b \cdot \cos \omega t$

$x = C_1 \cdot e^{i \cdot \omega \cdot t} + C_2 \cdot e^{-i \cdot \omega \cdot t}$

$x = A \cdot e^{i \cdot (\omega \cdot t + \varphi)}$

The kinetic energy Ec of a linear harmonic oscillator is:

$E_c = \dfrac{1}{2} \cdot m \cdot v^2 = \dfrac{1}{2} \cdot m \cdot \omega^2 \cdot A^2 \cdot \sin^2(\omega \cdot t + \varphi)$

The potential energy Ep is equal to the work required to move the oscillator from the initial position to the elongation position x.

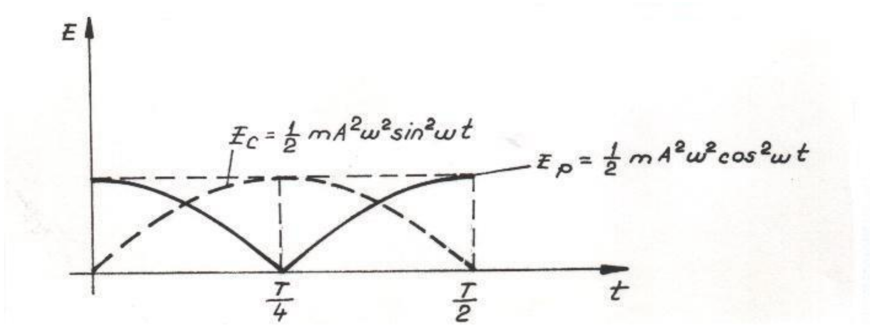
Therefore, the potential energy will be: $E_p = \int_0^x k \cdot x dx = \dfrac{1}{2} \cdot k \cdot x^2$

Taking into account the form of the elongation given above, we can write: $E_p = \dfrac{1}{2} \cdot k \cdot A^2 \cdot \cos^2(\omega \cdot t + \varphi)$

If $k = m \cdot \omega^2$, the last relation is also written:

$E_p = \dfrac{1}{2} \cdot m \cdot A^2 \cdot \omega^2 \cdot \cos^2(\omega \cdot t + \varphi) = 2 \cdot \pi^2 \cdot m \cdot \nu^2 \cdot A^2 \cdot \cos^2(\omega \cdot t + \varphi)$

The total energy E is: $E = E_c + E_p = \dfrac{1}{2} \cdot m \cdot \omega^2 \cdot A^2 = 2 \cdot \pi^2 \cdot m \cdot \nu^2 \cdot A^2$



DAMPED OSCILLATORY MOTION

Definition:

Oscillations are attenuated/damped when the amplitude decreases over time. They occur when there is a dissipation of energy under the action of frictional forces.

If a body moves in a liquid at a relatively low speed $v = \dot{x}$ then the resulting drag force is proportional to the velocity, i.e.: $\boxed{F_r = -r \cdot \dot{x}}$

where **r>0** is a coefficient that depends on the nature of the medium and the shape of the body in motion and is called **the resistance coefficient (or resistance coefficient).**

Damped oscillations are the oscillations of a system on which two forces act:

elastic force: $F_e = -k \cdot x$

and resistance force : $F_r = -r \cdot \dot{x}$

- To determine the law of oscillation, the equation of motion is used as follows:

We use : $m \cdot \ddot{x} = \frac{r}{m} \cdot \dot{x} + \frac{k.x}{m}$

- the depreciation coefficient δ

- own pulsation: ω_o - pulsation that a system would have only under the action of the elastic force.

The differential equation for damped oscillatory motion is: $\ddot{x} + 2 \cdot \delta \cdot \dot{x} + \omega_0^2 \cdot x = 0$ Or

$$\frac{d^2x}{dt^2} + 2 \cdot \delta \cdot \frac{dx}{dt} + \omega_0^2 \cdot x = 0$$

Differential equation for damped oscillatory motion:

$$\ddot{x} + 2 \cdot \delta \cdot \dot{x} + \omega_0^2 \cdot x = 0$$

The solution to this equation can be obtained if we make the substitution:

$$x(t) = z(t) \cdot e^{-\delta \cdot t}$$

and we get: $\ddot{z} + \left(\omega_0^2 - \delta^2\right) \cdot z = 0$

If elasticity prevails against the resistance of the environment: $\omega_0^2 \rangle \delta^2$

we can introduce the notation $\alpha^2 = \omega_0^2 - \delta^2$

where α represents the pseudopulsation which is a positive constant.

Consequently: $\ddot{z} + \alpha^2 \cdot z = 0$ (19)

thus, we obtain an equation of the form of the differential equation of harmonic oscillatory motion.

The solution can be written as follows: $z(t) = A \cdot \cos(\alpha \cdot t + \varphi)$ (20)

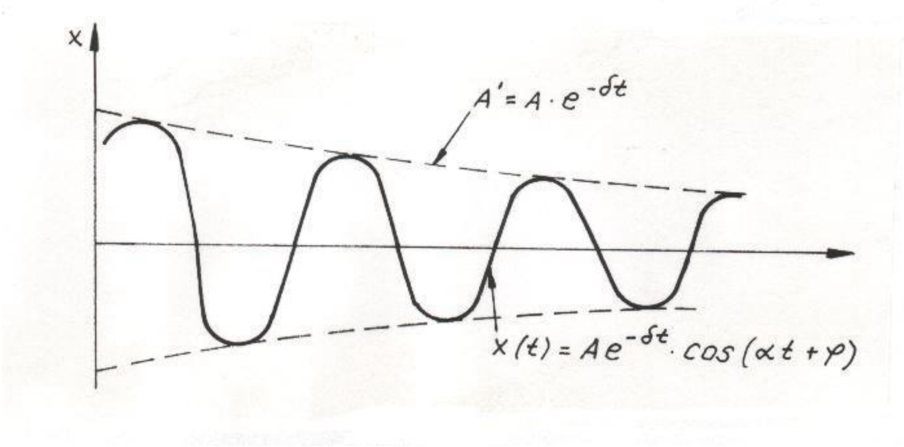
so the law of motion is: $x(t) = A \cdot e^{-\delta \cdot t} \cdot \cos(\alpha \cdot t + \varphi)$ (21)

If we note: $A'(t) = A \cdot e^{-\delta \cdot t}$ (22)

which represents the range of motion: $x(t) = A'(t) \cdot \cos(\alpha \cdot t + \varphi)$

Law of motion: $x(t) = A'(t) \cdot \cos(\alpha \cdot t + \varphi)$

The above expression shows that the elongation x varies periodically with an amplitude that decays exponentially with time.



(As (shown adjacent)

By analogy with harmonic oscillatory motion,

the pseudopulsation **of the damped oscillating motion is α**.

Similarly we define a **pseudoperiod** $T = \frac{2 \cdot \pi}{\alpha}$

Another quantity that characterizes damped oscillations is

the logarithmic decrement defined as the natural logarithm of the ratio of two successive amplitude values separated by a time interval equal to a pseudoperiod: $\lambda = \ln \frac{A'(t)}{A'(t+T)} = \ln \frac{A \cdot e^{-\delta \cdot t}}{A \cdot e^{-\delta(t+T)}} = \delta \cdot T$

If the resistance of the medium prevails against the elasticity, so that: $\omega^2 \langle \delta^2$

we write: $\beta^2 = \delta^2 - \omega^2 \rangle 0$

The differential equation of damped oscillatory motion becomes:

$\ddot{z} - \beta^2 \cdot z = 0$

with solution: $z(t) = C_1 \cdot e^{\beta \cdot t} + C_2 \cdot e^{-\beta \cdot t}$ (25)

so that the law of damped oscillatory motion will be written:

$x(t) = z(t) \cdot e^{-\delta \cdot t} = C_1 \cdot e^{-(\delta - \beta) \cdot t} + C_2 \cdot e^{-(\delta + \beta) \cdot t}$ (26)

Because in this case $\delta \rangle \beta$ it follows that each exponential term decreases monotonically in time.

The motion loses its periodic character and the amortization is aperiodic. If in the initial state the system is withdrawn from the equilibrium position, it returns asymptotically to the equilibrium state.

FORCED OSCILLATORY MOTION

Forced oscillations

Forced oscillations are the oscillations performed by a material point on which three forces are exerted:

- **An elastic force:** $F_e = -k \cdot x$
- **A resisting force:** $F_r = -r \cdot \dot{x}$
- **An external periodic force:** $F' = F_0 \cdot \cos \omega t$

Experience shows, and theoretical calculations confirm it, that in the first moments of the external force the oscillations no longer have a stationary character, i.e. a constant amplitude and impulse. In this case the pulsation and the amplitude vary according to a complicated law and the regime of these oscillations is called the transient regime.

The equation of motion is: $m \cdot \ddot{x} = -k \cdot x - r \cdot \dot{x} + F_0 \cdot \cos \omega \cdot t$

$$\ddot{x} + \frac{r}{m} \cdot \dot{x} + \frac{k}{m} \cdot x - \frac{F_0}{m} \cdot \cos \omega \cdot t = 0$$

We observe: $\frac{r}{m} = 2 \cdot \delta$; $\frac{k}{m} = \omega_0^2$; $\frac{F_0}{m} = f$

The differential equation of forced oscillation **or equation of forced oscillatory motion is:** $\ddot{x} + 2 \cdot \delta \cdot \dot{x} + \omega_0^2 \cdot x = f \cdot \cos \omega \cdot t$

The size δ is the damping coefficient
and ω_0 is the proper pulsation of the oscillations.
Under steady state, the solution of the Eq

$$\ddot{x} + 2 \cdot \delta \cdot \dot{x} + \omega_0^2 \cdot x = f \cdot \cos \omega \cdot t \qquad (29)$$

is: $x = A \cdot \cos(\omega \cdot t + \varphi)$ (30)

where the constants A and φ must be determined according to the dimensions of ω and f that are involved in equation (29).

Differentiating equation (30) twice with respect to time and substituting formula (16), we obtain :

$$\left(\omega_0^2 - \omega^2\right) \cdot \cos(\omega \cdot t + \varphi) - 2 \cdot \delta \cdot \omega \cdot \sin(\omega \cdot t + \varphi) = \frac{f}{A} \cdot \cos \omega \cdot t$$

The last equality must be variable at all times.

At time t1 for which: $\omega \cdot t_1 + \varphi = 2 \cdot \pi$

that is : $\omega \cdot t_1 = 2 \cdot \pi - \varphi$

because $\cos(2 \cdot \pi - \varphi) = \cos \varphi$

it follows that $\omega_0^2 - \omega^2 = \frac{f}{A} \cdot \cos \varphi$ (32)

At time t2 such that $\omega \cdot t_2 + \varphi = \frac{\pi}{2}$

because $\cos\left(\frac{\pi}{2} - \varphi\right) = \sin \varphi$

relation (31) becomes: $2 \cdot \delta \cdot \omega = -\frac{f}{A} \cdot \sin \varphi$

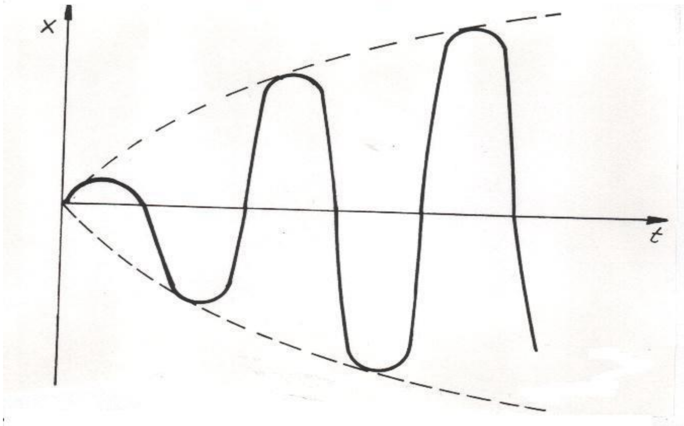
Squaring the last two relations and adding them, we get: $A = \frac{f}{\sqrt{\left(\omega_0^2 - \omega^2\right)^2 + 4 \cdot \delta^2 \cdot \omega^2}}$

Dividing (33) by (32) we get: $tg\varphi = \frac{2 \cdot \delta \cdot \omega}{\omega^2 - \omega_0^2}$

The relations obtained solve the problem in such a way that in steady state, the solution of equation (29) is:

$$x = \frac{f}{\sqrt{\left(\omega_0^2 - \omega_2\right)^2 + 4 \cdot \delta^2 \cdot \omega^2}} \cdot \cos\left(\omega \cdot t + arctg \frac{2 \cdot \delta \cdot \omega}{\omega^2 - \omega_0^2}\right)$$

If the body is initially at rest and an external periodic force begins to act on it, then it begins to perform forced oscillations, the amplitude of which increases until it reaches the maximum value given by relation (20).



From relations (34) and (35) we see that the amplitude A and the initial phase of the forced oscillations depend on the pulsation of the external force.

The value of the pulsation of the external force is called **resonance pulsation** and **the phenomenon of the development of a forced oscillation of maximum amplitude under the action of the external force is called in this case RESONANCE.**

The resonance pulse is obtained from the extreme condition $\frac{dA}{d\omega} = 0$ and performing the derivation we obtain $\omega_{rez} = \sqrt{\omega_0^2 - 2 \cdot \delta^2}$

The maximum value of the amplitude is called **the resonance amplitude** and is obtained by substituting the value of the resonance pulse in the expression $A_{rez} = \frac{f}{2 \cdot \delta \cdot \sqrt{\omega_0^2 - \delta^2}}$

If the middle resonance is zero

then from relation (23) we obtain: $\omega_{rez} = \omega_0$

that is, in this case, resonance is obtained when the pulsation of the external periodic force is equal to the pulsation of the oscillation.

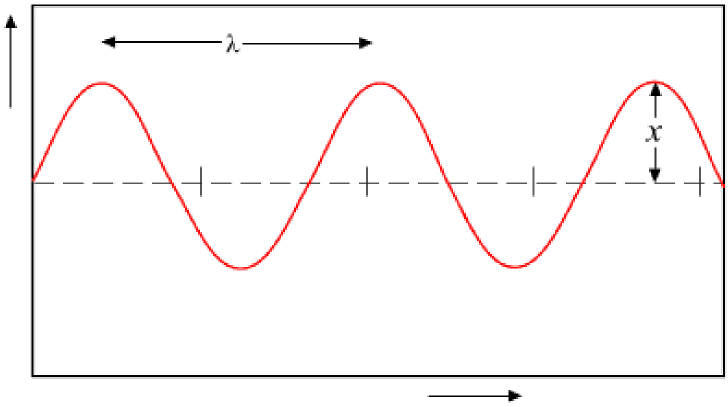
WAVE THEORY

INTRODUCTION TO WAVE THEORY

Definition: The locus of all points that have the same phase is called a WAVE.

- λ- the wavelength is the minimum distance between two points in space that oscillate in phase

x - the amplitude



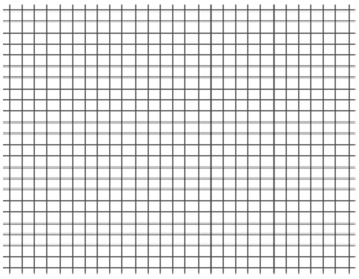
CLASSIFICATION OF WAVES

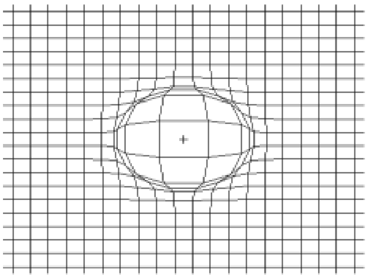
Definition:

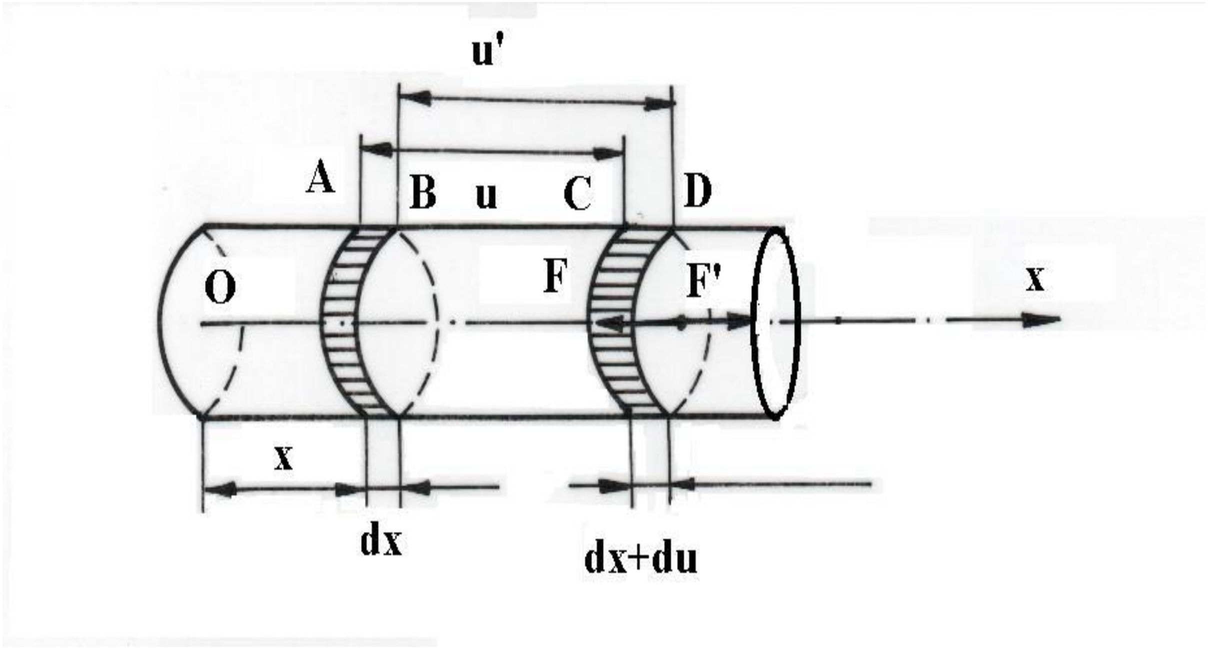
The set of oscillations of the material point of an elastic medium is called an elastic wave.

LONGITUDINAL WAVES

Waves for which the instantaneous velocity of each particle is parallel to the direction of wave propagation at the points where the particle is located. When a longitudinal wave propagates, local pressure vibrations are created.







If in the wire a disturbance propagates along the Ox axis, then the element dx deforms (elongation or compression) according to Hooke's law and gives rise to the force: $F = SE\frac{\partial u}{\partial x} = k\frac{\partial u}{\partial x}$

(4)

Consider the disturbance propagating along an elastic wire where longitudinal waves propagate in the Ox direction.

They produce local elastic deformations.

The forces exerted on the different sections are different so that the section S to the left of the element (dx + du) experiences the force F and the section S' to the right of the element (dx+ du) experiences the force F', their resultant being: $F' - F = \Delta F = \frac{\partial F}{\partial x} \cdot \Delta x$ (5)

Apart from the distortion effect, the two forces have an acceleration effect through their resultant.

We can write Newton's second law:

$$\Delta m \cdot \frac{\partial^2}{\partial t^2} = F + \Delta F - F = \Delta F \qquad (6)$$

But F = F(x), so that $F(x) + \Delta F = F(x + \Delta x)$

Then write the Taylor series expansion of the force F in the form:

$$F(x + \Delta x) = F(x) + \Delta x \cdot \frac{\partial F}{\partial x} + \Delta x^2 \cdot \frac{\partial^2 F}{\partial^2 x^2} + \ldots = 0 \qquad (7)$$

Higher order terms are neglected.

The force variation has the form: $\Delta F = \frac{\partial F}{\partial x} \cdot \Delta x$ (8)

and at the same time $\Delta m \cdot \frac{\partial^2 u}{\partial t^2} = \frac{\partial F}{\partial x} \cdot \Delta x$ (9)

Considering the warping effect, a second relationship between x and u is obtained: $\frac{E}{S} = E \cdot \varepsilon$

or $\sigma = E \cdot \varepsilon$

The partial differential equation for longitudinal elastic waves is: $\frac{\rho}{E} \cdot \frac{\partial^2 u}{\partial t^2} = \frac{\partial^2 u}{\partial x^2}$

(15)

The solution to this equation is: $u = f_1(x - ct) + f_2(x + ct)$ **(16)**

where f_1 and f_2 are arbitrary functions and

c is the propagation speed of longitudinal elastic waves:

$$c = \sqrt{\frac{E}{\rho}} \qquad \mathbf{(17)}$$

So we can write: $\boxed{\frac{1}{c^2} \cdot \frac{\partial^2 u}{\partial t^2} = \frac{\partial^2 u}{\partial x^2}}$

If we consider propagation in any direction or if it is wave in space, we can show that the equation for wave propagation in space is: $\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}=\frac{1}{c^2}\cdot\frac{\partial^2 u}{\partial t^2}$ (18)

and the left-hand member function is the Laplacian:

So we can write the partial differential equation of waves for their propagation in space

$$\Delta u=\frac{1}{c^2}\cdot\frac{\partial^2 u}{\partial t^2} \tag{19.1}$$

Or

$$(\Delta-\frac{1}{c^2}\cdot\frac{\partial^2}{\partial t^2})u=0 \tag{19.2}$$

In the equations in which $\frac{\partial u}{\partial t}$ the phenomenon of absorption of attenuated waves appears.

Partial differential equations for the description of waves

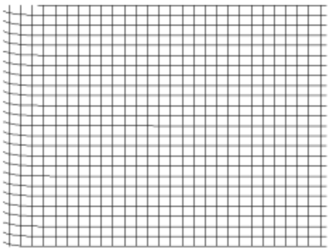
- **partial differential equation of elastic waves** $\frac{1}{c^2}\cdot\frac{\partial^2 u}{\partial t^2}=\frac{\partial^2 u}{\partial x^2}$
- **partial differential equation for wave propagation in space** $\frac{\partial^2 u}{dx^2}+\frac{\partial^2 u}{dy^2}+\frac{\partial^2 u}{dz^2}=\frac{1}{c^2}\cdot\frac{\partial^2 u}{\partial t^2}$

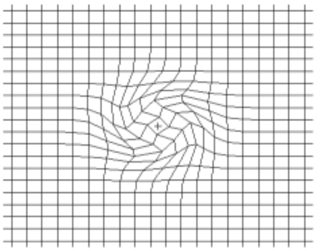
c is the propagation speed of longitudinal waves

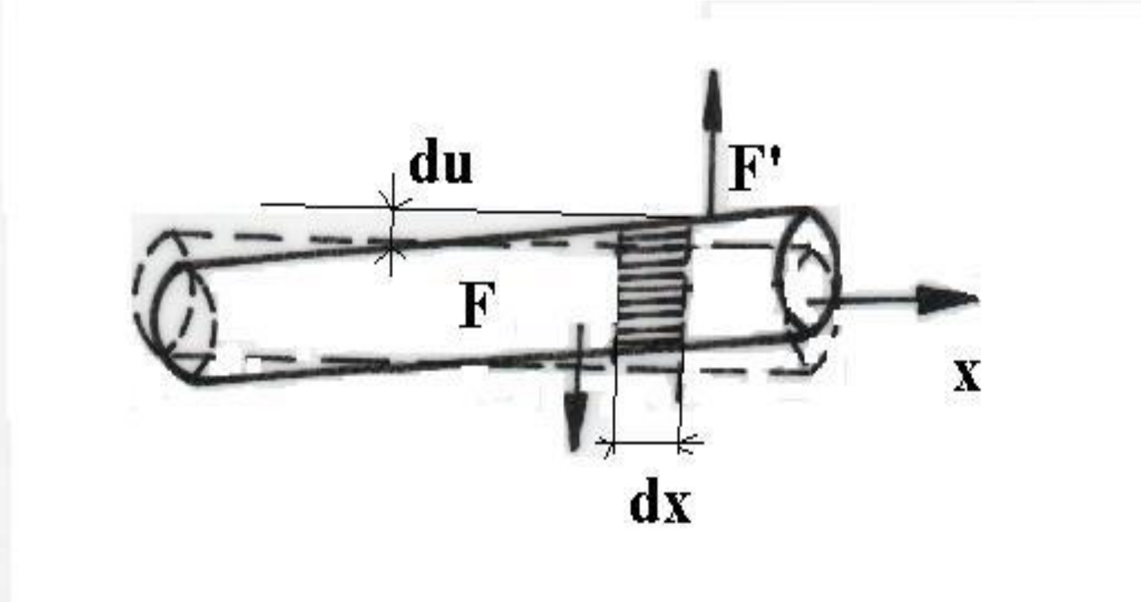
$$c=\frac{1}{\sqrt{\varepsilon_0\mu_0}}=2{,}997924\cdot 10^8\,\frac{m}{s}$$

TRANSVERSAL WAVES

Waves for which the instantaneous velocity of a particle is perpendicular to the direction of wave propagation







Consider a bar which, in the unformed state, is drawn with a dashed line as shown in the figure.

If the bar is struck transversely, it will begin to vibrate and at some point it will be in a position determined by the solid line in the figure.

An elementary section of the bar will move transversely to the equilibrium position, after its deformation, by the value of.

Section dx is subjected to forces F' and F which act tangentially to the surfaces S' and S of the sections and produce a shearing deformation.

This shear deformation will be characterized by the magnitude:

$$\gamma = \frac{\partial u}{\partial x} \tag{30}$$

The shear strain is proportional to the tangential force per unit area

$$\gamma = \frac{\partial u}{\partial x} = \frac{1}{G}\frac{F}{S} \qquad (31)$$

Therefore, the force acting on the considered medium in the case of transverse propagation of elastic waves has the form:

$$F = G.S.\frac{\partial u}{\partial x} \qquad (32)$$

G is called the shear modulus.

The resultant of the forces F' and F is written:

$$F' - F = \frac{\partial F}{\partial x} dx \qquad (33)$$

and produces an accelerator effect on the element dx which, according to the second principle of dynamics, is written: $\frac{\partial F}{\partial x} dx = \rho.S.dx.\frac{\partial^2 u}{\partial t^2}$ (34)

In this relation ρ the density of the medium is taken into account and S is the section of the bar at a given time, so we can write:

$$\frac{\partial F}{\partial x} = \rho.S.\frac{\partial^2 u}{\partial t^2} \qquad (35)$$

Since the force has the form: $F = G.S.\frac{\partial u}{\partial x}$

thus: $$\frac{\partial F}{\partial x} = G.S.\frac{\partial^2 u}{\partial x^2} \qquad (36)$$

And thus we obtain the partial differential equation of transverse wave propagation in a bar: $\frac{\rho}{G}\frac{\partial^2 u}{\partial t^2} = .\frac{\partial^2 u}{\partial x^2}$ (37)

where the speed of propagation of transverse waves is $v = \sqrt{\frac{G}{\rho}}$

The wave equation becomes: $\frac{1}{v^2}\frac{\partial^2 u}{\partial t^2} = .\frac{\partial^2 u}{\partial x^2}$ **(38)**

The wave equation in the three-dimensional case becomes:

$$\frac{1}{v^2}\frac{\partial^2 u}{\partial t^2} = .\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}$$
$$\frac{1}{v^2}\frac{\partial^2 u}{\partial t^2} = \Delta u \qquad (39)$$

where ∆u is called the Laplacian of the function u.

The solution of this equation has the form: $u(x,t) = f_1(x - vt) + f_2(x + vt)$

EQUATION AND SOLUTION OF THE EQUATION WHERE

the wave time equation $\omega^2 + \frac{1}{T}\frac{d^2T}{dt^2} = 0$

Temporary solution $T = C_1 e^{i\omega t} + C_2 e^{-i\omega t}$

the spatial wave equation $\frac{1}{X}\frac{d^2X}{dx^2} + k^2 X = 0$

Spatial solution $X = D_1 e^{ikx} + D_2 e^{-ikx}$

The general solution of the wave equation $\mathrm{u(x, t)} = e^{\pm i(\omega(\pm kx)}$

THERMODYNAMICS

The object of thermodynamics is the study of the physical laws of macroscopic systems, laws related to the thermal processes existing in these bodies, the law of the evolution of these systems and especially of their behavior at equilibrium.

The physical system studied can consist of a gas, a solid body with elastic properties, electromagnetic radiation at thermal equilibrium.

Thermodynamics is based on three very general principles, which summarize the results of a large number of experiments of a certain type: they are negative experiments, namely the failure of attempts to make machines work for free. Thus, the two principles of thermodynamics assume that certain major classes of phenomena cannot occur. The first principle denies the possibility of converting heat entirely into mechanical work.

STATE OF A THERMODYNAMIC SYSTEM. QUANTITIES THAT CHARACTERIZE THE THERMODYNAMIC SYSTEM

THE THERMODYNAMIC SYSTEM is a portion of the universe bounded so that the macroscopic objects (bodies or fields) it contains interact with the environment as a whole.

ISOLATED SYSTEM is a thermodynamic system in which there is no exchange of energy or any external component.

ISOLATED ADIABATIC SYSTEM is a system that can only interact with the outside by performing work.

CLOSED SYSTEM is a system in which there is no exchange of substances between the system and the outside world.

1. **STATIONARY STATES** are states that have the following characteristics:

- the parameters that define them do not vary over time,
- have constant gradients for characteristic quantities,
- presents an energy consumption.

STEADY STATES are states of equilibrium or non-equilibrium.

1.1. **EQUILIBRIUM STATES** are states that have the following characteristics:

- the intensive parameters have the same value in every point of the system,
- the state of the system does not vary over time, does not change external conditions,
- the state of the system does not change as long as the system is not crossed by external flows involving the transport of substance.

1.2. UNBALANCED STATES are states that have the following characteristics:

- have non-zero gradients for the characteristic quantities,
- their parameters change over time.

STATUS PARAMETERS

The state of a thermodynamic system is characterized by the values that certain parameters take at a given moment.

STATE PARAMETERS are represented by a number of physical quantities that characterize its macroscopic properties.

The parameters used to describe the state of the system may depend on each other. We choose a minimum number of parameters to describe the condition.

The parameters can be:

EXTERNAL PARAMETERS: which depend only on the generalized coordinates of the external fields with which the system interacts – the gravitational field or any force field can be an external parameter.

INTERNAL PARAMETERS : when they also depend on the generalized coordinates external bodies than the average values of the coordinates and velocities of the particles.

THE PARAMETERS CAN BE MECHANICAL OR THERMODYNAMIC.

The mechanical parameters can be:

- **force parameters** that depend on the external forces acting on the system (force, pressure)

- **position parameters -** which show the position of the system relative to the outside (volume, area).

(C.Motoc, Physics, vol.I-Classical Physics, Ed.All, 1997)

THERMODYNAMIC PROCESSES can be classifed as follows:

REVERSIBLE PROCESSES are processes in which the system can return to its original state only if it passes through the same intermediate states as in direct processes.

IRREVERSIBLE PROCESSES are processes in which the initial state cannot be reached by the same path, and the intermediate states are non-equilibrium states.

QUASISTATIC PROCESSES are very slow processes, processes for which intermediate states can be considered equilibrium states.

NONSTATIC PROCESSES are processes in which the transition from the initial state to the final state occurs through a sequence of non-equilibrium states.

POSTULATES OF THERMODYNAMICS

FIRST POSTULATE: An isolated system always reaches after a time interval the state of thermodynamic equilibrium and can never leave this state by itself (if the parameters are kept constant).

The first postulate of thermodynamics leads to the existence of a whole series of state functions of the system in thermodynamic equilibrium. It is also called **the general principle of thermodynamics.**

SECOND POST: Two systems A and B that can exchange heat are in thermal contact. If thermodynamic systems placed in contact do not exchange heat with each other, they are said to be in a state of thermal equilibrium.

The second postulate states that thermal equilibrium is transitive.

It follows that the state of thermal equilibrium of a system is given by the external parameters and by a physical quantity called empirical temperature where all the internal parameters of a system in a state of thermodynamic equilibrium are a function of the external and empirical temperature parameters. At thermal equilibrium, the empirical temperature has the same value for all systems that are in thermal contact.

THE SECOND POSTULATE OF THERMODYNAMICS can be stated as follows: all internal equilibrium parameters (Bi) of a physical system are a function of external parameters (AK) and temperature (T), namely: Bi = Bi (A1, A2, … An, T).

This postulate regarding the existence of temperature as a particular state parameter of an equilibrium system is called <u>the ZERO PRINCIPLE of thermodynamics</u> because like the

first principle and also the second principle which establishes the existence of a state function, this principle establishes the existence of temperature, as a function of the state of the systems in equilibrium.

THE ZERO PRINCIPLE OF THERMODYNAMICS

Statement: "The zero principle of thermodynamics makes it possible to define temperature as a measurable physical quantity by unambiguously association of numerical values. »

APPLICATION OF THE ZERO PRINCIPLE OF THERMODYNAMICS: TEMPERATURE MEASUREMENT

Practical determination of temperature requires the use of a temperature scale related to the thermal properties of a substance. We consider that the thermodynamic state of the substance is completely determined by an external parameter X and an internal parameter Y. The empirical temperature θ is:

$$\theta = \theta\ (X, Y) \qquad (1)$$

If Y = constant, we obtain: $\theta = \theta\ (X)$

A standardized system, called THERMOMETER, can be established so that the empirical temperature θ depends linearly on a state parameter:

X: $\theta = a + bX$

To determine the constants a and b, we must fix two reference isotherms, to which we assign the values θ1 and θ2:

$$a = \frac{\theta_1 X_2 - \theta_2 X_1}{X_2 - X_1} \quad ; \ b = \frac{\theta_2 - \theta_1}{X_2 - X_1} ; \quad \theta = \frac{\theta_1 X_2 - \theta_2 X_1}{X_2 - X_1} + \frac{\theta_2 - \theta_1}{X_2 - X_1} X$$

Based on this reasoning, several temperature scales have been developed.

EMPIRICAL TEMPERATURE - PROPERTIES

Empirical temperature is a scalar parameter with the following properties:

- It is an **intensive parameter** that takes the same values for the equilibrium states of a set of isotherms regardless of the thermodynamic system to which it belongs.
- States that are not in a thermodynamic equilibrium relationship have different temperatures.

By using an appropriate measurement method, it is possible to associate an empirical temperature value with each of the sets of isothermal states.

EFFICIENT EMPIRICAL TEMPERATURE MEASUREMENT:

Necessary conditions for effective empirical measurement of temperature

- the choice of the thermometric body
- the choice of thermometric properties
- determining the initial value A0 and the final value A
- choosing a reference set Mo of isotropic systems having as a representative element a state of maximum conductivity of a certain system chosen expressly for this purpose. This state can be, for example, that of a system consisting of pure water, pure ice, and pure water vapor. The three states are in thermodynamic equilibrium and form the triple point of water.

EMPIRICAL TEMPERATURE MEASUREMENT SCALES

KELVIN SCALE:

This temperature measurement scale is fixed at θ_0=273.16

The unit is called Kelvin (K) and is the temperature of the triple point of water.

This empirical temperature measurement scale has an undefined 0 point because the temperature 0 K is practically unreachable.

Technically now we can measure the value of 0K which is at the same time (- 273 ^{o}C).

Therefore, we have the right to name it

KELVIN'S EMPIRICAL SCALE

It was proposed in 1848 by the English scientist Lord Kelvin.

Nothing can be cooled that much, even if a temperature of 0.000007 K was achieved.

CELSIUS SCALE:

In practice, the most commonly used is the Celsius scale whose temperatures are related to those of the Kelvin scale by the equation: $\theta_{celsius} = \theta_{Kelvin} - 273{,}16$

The unit is called degree Celsius (℃) and is the temperature of the triple point of water.

The Celsius scale establishes the following reference isotherms:

- the isotherm corresponding to the equilibrium between ice and liquid water, at a pressure p_0 = 1 atm, for which θ_1 = 0 °C

- the isotherm corresponding to the equilibrium between liquid water and water vapor at a pressure $p_0 = 1$ atm., for which we will consider the empirical temperature $\theta_2 = 100$ °C

FAHRENHEIT SCALE

In the United States and other English-speaking countries except Great Britain, the Fahrenheit scale is widely used.

The relationship between the Fahrenheit temperature and the Celsius scale is the following:

$$\theta_{Fahrenheit} = \frac{9}{5}\theta_{celsius} + 32$$

The Fahrenheit scale establishes the same reference isotherms as the Celsius scale, but assigns them the temperatures $\theta_1 = 32$ F and $\theta_2 = 212$ F.

In 1724, Gabriel Fahrenheit used for the first time the mercury as a thermometric liquid. Mercury expands greatly, does not adhere to the container and remains in the liquid state of aggregation for a wide range of temperatures.

The thermometer indicates 32°F at the freezing point of water and 212°F at the boiling point at normal atmospheric pressure.

Usually, this temperature scale is used in the United States.

The Fahrenheit scale is used today in the United States, Belize, and the Cayman Islands.

In Canada, it is, by law, usable as an additional scale. In other Commonwealth countries, where it was widely used, it was replaced by the Celsius scale in the second half of the 20th century.

EXPANSION

Temperature measurement is based on the reproducible properties of thermodynamic systems, such as:

- Thermal expansion of solids, liquids and gases (thermometers)
- The influence of temperature on the contact voltage between two conductors (thermocouples)
- The influence of temperature on electrical resistance for conductors and semiconductors (resistance thermometers, thermocouples or thermoelements)

Expansion is the phenomenon on which temperature measurement with thermometers is based. Expansion is the phenomenon by which a body changes its volume due to heat exchange without producing work.

→ SOLIDS:

- **Linear: $l=l_o(1+ \alpha \cdot \Delta t)$**
- **Area: $A=A_o(1+ 2\alpha \cdot \Delta t)$**
- **Volume: $V=V_o(1+ 3\alpha \cdot \Delta t)$**

where $\alpha = \Delta l / l_o \Delta t$, the coefficient of linear expansion

→ Fluids:

$\gamma = \Delta V / V_o\Delta t$, coefficient of volumetric thermal expansion ;

the relationship becomes, close to 0°C: $V=V_o(1+ \gamma t)$

ΔV = actual change in liquid volume due to a change in temperature.

INSTRUMENTS FOR TEMPERATURE MEASUREMENT

CLASSIC THERMOMETERS

1. CLINICAL MERCURY THERMOMETERS can be used to measure human body temperature. They have an obstruction (a narrow neck) at the bottom of the tube so that the liquid does not return to the tank immediately after the measurement.

2. EASY THERMOMETERS - the temperature is measured using the expansion of the liquid: the higher the temperature, the more the liquid expands and the indicated value increases.

Mercury is used in thermometers because of its unique properties. It can measure a wide range of temperatures from -40℃ to 356℃, and up to 570℃ under pressure, in the liquid state.

It expands regularly with changes in absolute temperature. It works well in capillary tubes, does not "wet" and is easily obtained in pure form.

Other substances used are:

- **alcohol** - which can be used at temperatures below mercury (-80°C) and
- **pentane** (C_5H_{12} - alkane) - which can be used at (-200°C).

3. MAXIMUM AND MINIMUM THERMOMETERS - record the lowest or highest temperatures. They are often combined into a single maximum and minimum thermometer.

3.1. THE AUTOMATIC REGISTERING MAXIMUM THERMOMETER by Daniel Rutherford (invented in 1794) consists of a mercury tube inside which is a small piece of steel located above the liquid level.

Because the liquid expands when the temperature rises, it pushes the steel piece. When the liquid contracts, the piece stays in place, marking the highest temperature reached since the thermometer was attached.

The instrument can be reset with a magnet.

3.2. THE MINIMUM THERMOMETER contains alcohol instead of mercury.

Inside is a small piece of glass, the upper end of which reaches the surface of the liquid. As the alcohol contracts, the glass is dragged down by the alcohol. During expansion it maintains its position, its extremity indicating the lowest temperature reached.

- **THE METAL THERMOMETER** has two metal strips with different coefficients of thermal expansion which are welded together and twisted in a spiral inside, the metal having the higher temperature coefficient.

As the inner lamella expands further when heated, the spiral unravels. Similarly, a reduced temperature causes spiral twist. A needle designed to indicate temperature variations may be attached to such an instrument.

- **The GAS THERMOMETER** is more sensitive at a high coefficient of gas expansion. It measures temperature variations by recording the corresponding pressure variation. However, this type of thermometer tends to be large and bulky, requiring large quantities of liquids whose temperature needs to be measured.

LIQUID-IN-GLASS THERMOMETER

This type of thermometer is used to measure the local temperature in the range of 200-1050 ^oC.

Working principle of glass thermometers fluid is based on the expansion of a liquid in a confined space.

These thermometers are made of transparent glass, with a good thermal quality and a maximum expansion coefficient of 2.55.

The thermometric liquid can be:

- pentane: 200 ... 20 ^{o}C;
- alcohol: 110 ... 75 ^{o}C;
- toluene: 80 ... 100 ^{o}C;
- mercury: 35 ... 800 ^{o}C;
- gallium alloy: 0 ... 1050 ^{o}C.

DIFFERENT TYPES OF THERMOMETERS

- a) **The massive capillary thermometer** has a capillary with a diameter approximately equal to the reservoir.
- b) **Tubular thermometer** has the ladder and the tank mounted on the end of the rod, in the extension of the tubular body. The graduated scale is drawn on an opaque plate inside the tubular body.
- c) **The unprotected capillary thermometer** has at the upper end a bent capillary tube fixed to a plate on which the graduated scale is drawn.

METAL RESISTANCE THERMOMETERS

The operation of metal resistance thermometers is based on the variation of the electrical resistance of a temperature conductor:

$$R_T = R_{T_0}\left[1+\alpha(T-T_0)+\beta(T-T_0)^2+\ldots\right] \qquad (1)$$

where: RT – conductor resistance at temperature T°C;

RT_0 – conductor resistance at base temperature To (usually 0 ^{o}C);

α, β - the coefficients that depend on the nature of the material.

The change in resistance is detected and converted into an electrical signal, usually by bridge circuits. The main measurement range is between 100°C-500°C.

The metal resistance thermometer is based on a metal wire with the property that its resistance increases **/decreases with the increase/decrease in temperature.**

Conditions that must be fulfilled by the materials used as a sensor:

- to have a high resistivity;
- to have the same properties over the entire temperature range;
- resistance to corrosion;
- to be stable over a temperature range;
- withstand repeated temperature cycles;
- to have reproducible resistance characteristics - temperature;
- to react quickly to temperature changes;
- can be used to produce very thin yarns.

The material used to produce the metallic resistance is characterized by a temperature coefficient α which represents the slope of the straight line connecting the points that give the resistance at 0 ^{o}C – 100 °C.

$$\alpha = \frac{R_{100} - R_0}{100 R_0}$$

where: α- temperature coefficient

R100 - resistance to 100 °C [Ω]

R0 - resistance at 0 °C [Ω]

Common materials for metal resistance are pure metals (platinum, nickel, copper) and metal alloys such as nickel-iron.

High-performance materials with a high temperature coefficient and reproducible values of resistance over a wide range of temperatures are used to make the thermistors (resistance thermometer).

Usually, the following materials are used: platinum Pt (-200 ^{0}C to +600^{0}C), nickel (Ni) (- 60 ^{0}C to + 180 ^{0}C) or, more rarely, copper (Cu) and gold (Au) or silver (Ag) alloys are used.

THERMISTORS

They are based on the variation of electrical resistance of semiconductor materials as a function of temperature.

The principle of operation is the same as that of the metal resistance sensor, the difference being in the material from which the resistance is made.

Depending on the semiconductor material, they are classified as follows:

- **negative temperature coefficient thermistors** in which resistance decreases as temperature increases (most of them have a negative temperature coefficient);
- **positive temperature coefficient thermistors**, in which resistance increases as temperature increases.

Thermistors are semiconductors (with a negative temperature coefficient of variation) formed from mixtures of metal oxides or pure germanium. The variation of electrical resistance with temperature can be described by the equation:

$$R_\theta = R_0 e^{-b\theta} = R_0\left(1 - \beta\theta + \frac{\beta^2}{\theta^2} - \cdots\right) \qquad (1)$$

where Rθ- resistance of the thermistor to temperature θ;

R0- the resistance of the thermistors at the initial temperature θ0 ;

θ- the temperature at a given moment;

b – coefficient that depends on the material (b = 0.03 to 0.06 deg^{-1});

β- coefficient that depends on temperature (proportionality factor)

$$\beta = \frac{1}{R_0} = \frac{dR_0}{d\theta} = -\frac{b}{\theta^2} \qquad (2)$$

The coefficient β is negative. It strongly depends on the temperature, being about 10 times higher than that of the thermistors.

The application is generally from - 70 °C to + 300 °C.

TEMPERATURE MEASUREMENT WITH THERMOCOUPLE

Materials that together exhibit a Seebeck effect form a thermocouple. In a metal wire whose ends have different temperatures TA > TB there is an electric potential difference U_{AB} caused by the fact that the conduction electrons at the higher temperature end have a higher kinetic energy and will propagate towards the cooler end. This way, the hot end will have a positive charge and the cold end of the wire will be negatively charged. Note that, if the moving charge carriers are holes, positive charges, then the hot end will have a negative charge and the cold end a positive charge.

This is why the thermoelectric effect or Seebeck effect is used to determine the type of free charge carriers in a semiconductor. The thermoelectromotive voltage (ttem) that appears UAB is directly proportional to the temperature difference between the ends of the wire: U_{AB} = VA - VB = S (TA - TB) (1)

where S is the Seebeck coefficient, a property of the material from which the thread is rolled.

The solution to the problem was to extend the thermoelectrodes through other conductors of the same nature, generally of the same material. In this way, at the contact between the thermocouple wires and the extension leads, the formation of a thermocouple is not possible and therefore the thermoelectromotive force does not occur.

These wires are called compensating wires and are completely separated from the thermocouple, the connection being made only when mounting the thermocouple.

The function of the compensation cable is to move the cold junction from near maximum temperature to a constant temperature location.

The cold junction will be formed at the junction between the compensation cable and the connecting cable. Thermocouples are made of different metals or alloys.

The thermoelectromotive voltage of various thermocouples depends on the material from which the thermoelectrodes are made as well as the temperature of the hot and cold junctions.

The relationship between temperature and thermoelectromotive force can be expressed by a quadratic equation: $E = a + bt + ct^2$

where E is the resultant thermoelectromotive force, when t is the hot junction temperature and the cold junction temperature is constant (typically 0°C) and a, b and c are three constants whose values are determined by measuring the thermoelectromotive voltage at known fixed temperatures (solidification temperature of antimony, silver and gold). The value of the constants a, b and c depends only on the material of the thermoelectrode. Curves representing the relationship between temperature and thermoelectromotive voltage are called international curves.

Each type of thermocouple has its own international curve.

THE FIRST PRINCIPLE OF THERMODYNAMICS

The internal energy U of a thermodynamic system is a state quantity whose variation ΔU is equal to the difference between the heat Q and the work W changed by the system with the external environment:

$\Delta U = Q - W = U2 - U1$

For closed systems that do not exchange substances with the environment, the relationship is:

$\Delta U = U2 - U1 = Q - W$

where $\Delta U = U2 - U1$ is the change in the internal energy of the system in the process from state 2 to state 1.

Q is the heat received ($Q > 0$) or

heat transferred ($Q < 0$) by the system,

the work done by the system ($W > 0$) or

the work done on the system ($W < 0$)

For open thermodynamic systems, the expression for the first law of thermodynamics is:

$\Delta U = U2 - U1 = Q - W = Q – W + T$

Where T is the energy of the transport system received or transmitted by the exchange of particles with the medium.

If the thermodynamic process is elementary, or infinitesimal, we write:

$\delta U = \delta Q - \delta W + \delta T$

We note δQ, δW and δT to emphasize that these are elementary, process quantities, not exact total differentials.

For **closed thermodynamic systems**:

For N = const. we can write $dU = \delta Q - \delta W$

For **thermodynamic processes that are cyclic** we can write:

$dU=0$, $\delta Q - \delta W = 0$, $\delta W = \delta Q$

This equality leads to the conclusion that it is impossible to obtain a heat engine that can perform mechanical work in a cyclic process without receiving heat from the outside [a perpetuum mobile de premier case I].

Since the internal energy U is a state function, dU is an exact total difference, thus we can write: $\oint dU = 0$

We can say that the internal energy U characterizes the energy reserve of a thermodynamic system, which - in principle - can be transferred in the form of heat or by mechanical work.

For thermodynamic systems located in electric or magnetic fields that are polarized or magnetized.

For the polarization of the unit volume of a homogeneous dielectric, located in an electric field with intensity E, the mechanical work performed is:

$\Delta Wp = EdP$

where P is the polarization vector which depends on the electric field strength E and the temperature T

$P=P(E1T)=D-\varepsilon 0E=\varepsilon 0(\varepsilon 0-1)E= \lambda e(T).\varepsilon 0E$

where λe (T) = εr (T) -1 is the electrical susceptibility of the substance.

The work done to magnetize unit volume of an isotropic magnetic substance is: $\delta\ Wm=HdM$

where H is the magnetic field strength and M is the magnetization:

$M=M(H,T)=B-\mu 0H=\mu 0H(\mu r-1)=\lambda m(T)\mu 0H$

where λm (T) - the magnetic susceptibility of the substance.

Thus, a simple thermodynamic system, located in external electric and magnetic fields, can be considered as a system characterized by three generalized forces:

$F1=p, F2=E, F3=H$

The three generalized coordinates are: $x1=V, x2=p, x3=M$

and the mechanical work is: $\delta W = \Sigma Fi.xi= p.dV+H.dp+H.dM$

If μj is the chemical potential against a single molecule and Nj is the number of molecules of component j in the system, then it follows that the chemical potential is a generalized force and the number of molecules can be interpreted as a generalized coordinate: $\delta T= \Sigma\mu i.dNi$

THE SECOND LAW OF THERMODYNAMICS

THOMSON'S FORMULATION

In a cyclic monothermal transformation the system cannot transfer mechanical work to the outside. If the cyclic monothermal transformation is also irreversible, the system receives mechanical work from the outside.

CLAUSIUS' FORMULATION

It is impossible to make an engine that works in a cyclic process that produces no other effect than the transfer of heat from a colder body to a hotter one.

KELVIN'S FORMULATION

It is impossible to perform a cyclic process that produces no other effect than extracting heat from a reservoir and converting it into mechanical work.
Or: “there is no engine that runs cyclically from a single source of
the heat."

CARATHEODORY’S FORMULATION

Near any state of thermodynamic equilibrium of a system there are states that cannot be reached by an adiabatic process.

THE SECOND PRINCIPLE FROM THE STATIC POINT OF VIEW:

In an isolated system, processes occur in the direction of increasing thermodynamic probability, i.e. more ordered by more disordered states.

THE SECOND PRINCIPLE BY USING THE ENTROPY:

In an elementary reversible transformation, the ratio of the heat exchanged to the thermodynamic temperature of the source is a total difference which by definition is the entropy: $\Delta S = \Delta Q / T$.

Formulation of the second law of thermodynamics for irreversible processes or the law of increase of entropy

The entropy of an isolated system can never decrease: $\Delta S > 0$ or $S_B - S_A > 0$

THE THIRD LAW OF THERMODYNAMICS

FORMULATION of the third PRINCIPLE of thermodynamics:

the absolute entropy of the thermodynamic system tends to zero when the absolute temperature tends to zero Kelvin.

THE FORMULATION of the third PRINCIPLE of thermodynamics or Nernst's Theorem: the absolute zero isotherm coincides with the adiabatic one.

Experimental data led to the conclusion that the entropy of thermodynamic systems tends to a constant value when the absolute temperature T tends to absolute zero.

Max Planck postulated that as T tends to 0 K, entropy tends to zero: the absolute entropy of a thermodynamic system tends to zero as the absolute temperature tends to 0 K:

This ratio is one of the possible statements of the third law of thermodynamics.

THE CONSEQUENCES OF THE THIRD THERMODYNAMIC PRINCIPLE

1. Regardless of the process a thermodynamic system performs, its heat capacity cancels out with absolute temperature.

$$\lim_{T\to 0k} C = \lim_{T\leftarrow 0K}\left(T\frac{\partial S}{\partial T}\right) = \lim_{T\to 0K}\left(T\frac{\partial S}{\partial \ln T}\right) = 0$$

In particular, to obtain $\lim_{T\to 0K} C_v = \lim_{T\to 0K}\left(T\frac{\partial S}{\partial \ln T}\right) = 0\,;\ \lim_{T\to 0K}\left(T\frac{\partial S}{\partial \ln T}\right) = 0$

This means that even the temperature T → 0K the thermal equation of the ideal gas state is not valid.

2. It can be shown that for T → 0K, the coefficient of thermal expansion α and the thermal coefficient of pressure β tend to zero.

For example, for T → 0K, solids are no longer compressible.

3. T → 0K , the entropy of the system cannot be changed by an action, hence another formulation of the third law of thermodynamics : "The absolute zero isotherm coincides with the adiabatic one".

4. The physical meaning of the cancellation of the heat capacity at T = 0 K is: "The temperature of 0 K represents the state in which the system can no longer give heat under the conditions in which the minimum energy state is obtained."

5. Therefore, the validity of the third law of thermodynamics leads to the conclusion that; The temperature of 0 K is practically unreachable.

APPLICATIONS OF THE FIRST PRINCIPLE OF THERMODYNAMICS IN BIOPHYSICS

It has been experimentally demonstrated that:

- In phenomena that occur in a single form of energy, the amount of energy is conserved.
- In phenomena that transform one form of energy into another, the transformation is done in equivalent quantities.

In 1842 - 1850 R. Mayer, J.Joule and H.Helmholtz find that whenever the work done by a system is transformed into heat, or vice versa, between these forms of energy, there is an equivalence and the determination is made of the mechanical equivalent of calories. There is a quantitative relationship between the different types of energy considered.

Based on the first law of thermodynamics, a general law of energy conservation could be formulated, according to which energy cannot be created or destroyed, it can be transformed from one form to another only in equivalent amounts. Therefore, the first law of thermodynamics was called the principle of conservation of energy.

This principle shows the existence of a state parameter characteristic of any system called by Clausius (1850) the internal energy of the system U, which is a parameter that in each state of the system has a determined value. This parameter expresses the ability of the system to perform actions of any kind (mechanical, osmotic, chemical, electrical).

If the system has energy exchanges with the outside, its internal energy varies by an amount equal to the sum of all these exchanges.

When there is a variation in the energy of disordered motion (thermal agitation) of the molecules or in the interaction energies (disordered) of the molecules, the system exchanges heat with the outside Q, when there is a variation in the energy of ordered motion of a series of molecules of the system, the system exchanges mechanical work W with the outside so that macroscopic-scale displacements occur.

When chemical reactions take place in the system, the internal energy varies due to the reactions taking place, which is reflected outside through exchange of work or exchange of heat.

In the case of living organisms that are open systems, the transfer of energy between the system and the environment is also ensured by the exchange of substances.

With the exchange of molecules, all forms of energy associated with them are transferred.

The variation of the internal energy ΔU of a biological system, when passing from one state to another, will be given by the algebraic sum of the amount of heat Q and all forms of work Wm - mechanical, Wo-osmotic, Wc - chemical, changed. from this system with the environment, i.e.:

$$\Delta U = Q+W_m+W_c+W_0+...$$

The convention in biophysics and in equation (1) is developed as follows:

- (+) refers to the amount of heat and work received by the biological system and
- (-) refers to the amount of heat and work that is lost from the biological system.

The relation (1) represents a general formula for the first law of thermodynamics from which all the energy conservation equations for the various systems are derived.

Living organisms are systems whose internal energy can increase or decrease depending on different conditions (age, physiological state, etc.).

For a correct application of the first law of thermodynamics for living organisms, it must be taken into account that biological systems are open systems, so conservation of energy occurs only for the closed system consisting of the organism and its environment.

The law of conservation of energy for living organisms is as follows:

$$Em = W + Q + Ed \qquad (1)$$

When applied to an organism, the first law of thermodynamics takes the following form:

$$Em = W + Q + Ed \qquad (2)$$

where Em is the energy in the environment

W is the work done by the body

Q is the heat given off by the body

Ed is the energy stored in the body's reserves

If cold-blooded animals can obtain energy in the form of heat, the process is simplified if the bodies are at rest, so no mechanical work is performed ($W=0$) and the body has not eaten for at least 12 hours, i.e. it does not take energy from the environment ($Em = 0$).

Under these conditions, we can write: $0 = Q + Ed$ (3)

The above relationship shows that the body produces heat at the expense of its own energy reserves which are diminished by use: $Q= -Ed = Eu$ (4)

Eu is the energy used by the body.

The determination of heat production in the human body, in these extreme conditions mentioned above, constitutes the clinical test of the basal metabolism that defines the reference value to which the effect of the different factors that influence the metabolism, energy, is reported.

The main source of energy for living in the world is solar radiation.

It has been calculated to be 9.10^{22} kcal/s, of which only a very small fraction $\{1/(2.10^{9})\}$ is on the earth's surface and only a small percentage of it is taken up by plants and used to synthesizes from sunlight, carbon dioxide, mineral water and energy-rich organic substances (biosynthesis).

These organic substances were the source of energy for heterotrophic organisms which include man.

After primitive man began to use animal food, another stage of energy consumption arose between humans and green plants, so energy efficiency is lower.

As a result of the research, the conclusion is reached that, in general, the transformation of food of vegetable origin into food of animal origin involves a loss of energy of 80-90%.

But animal protein is a higher quality food than vegetable products.

APPLICATIONS OF THE SECOND PRINCIPLE OF THERMODYNAMICS IN BIOPHYSICS

If a system does mechanical, electrical, or osmotic work by decreasing its kinetic energy by an amount ΔU, the work done, $-W$ is less than ΔU, because some of the internal energy is transferred into thermal energy Q. This "degraded" energy is equal to the product of the absolute temperature T of the system and by the increase ΔS of a state parameter, called the entropy of the system.

If the first law of thermodynamics used the state parameter of the entire system called internal energy (U), Principle II introduces a new parameter that characterizes each state of a system called entropy (S), the peculiarity of which is that it increases through any spontaneous process.

Hence, the second law of thermodynamics also called the law of increase of entropy.

If the system is isolated, its entropy will increase over time, the evolution of the system going towards maximum entropy, where all the internal energy of the system has been converted into heat and can no longer be converted into mechanical work.

It results that, from the internal energy U of a system at temperature T, only a part can be transformed into mechanical work, which is called the free energy of the system F: $F = UT.S$ (5)

APPLICATIONS OF THE SECOND PRINCIPLE OF THERMODYNAMICS IN BIOPHYSICS FOR ISOLATED SYSTEMS

In isolated systems where the internal energy U is constant, the increase in entropy obviously implies the decrease in free energy according to the relations (F=U-TS): $\Delta F = \Delta U – T. \Delta S$

U= constant; $\Delta U = 0$

$\Delta S > 0 \rightarrow \Delta F = TS\ \Delta<0$ (6)

Thus, the second law of thermodynamics states that by any process that takes place in an isolated system, its free energy F decreases and its entropy S increases.

As stated in the first law of thermodynamics, the change in internal energy ΔU is given by: $\Delta U = QW$ (7)

which consists of two terms:

Q represents the heat exchange (heat received) with the outside due to the disordered motion of the molecules.

W represents the exchange of mechanical work (or other type of work) due to macroscopic ordered motion in the case of volume variation due to external pressures surface variation due to surface tension, of electric charge transport due to a potential difference (in relation to (7) W is negative).

If in equation (7) Q is the amount of heat absorbed by the system and W is considered the mechanical work W due to the volume change ΔV,

Then the relation becomes $\Delta U = Q - p.\ \Delta V$ (8)

During chemical transformations in the absence of mechanical work and at constant volume, the internal energy variation given by relation (8) becomes: $\Delta U = Q$

In this case, Q is the amount of heat resulting from the isochoric thermal effect (at constant volume). This amount of heat is measured using a bomb calorimeter that completely seals off the place where the chemical reactions take place.

APPLICATIONS OF THE SECOND LAW OF THERMODYNAMICS IN BIOPHYSICS FOR OPEN SYSTEMS

In the case of biological processes that take place in the free atmosphere under constant pressure, processes called isobaric for this reason, it is useful to use instead of the internal energy (U) the quantity called enthalpy:

$$\mathbf{H = U + HP} \qquad (9)$$

The enthalpy variation is:

$$dH = dU + p.dV + V.dp \qquad (10)$$

$dW = p.dV$ work done by the system.

If we consider the relationship: $dU = dQ + p.dV$

then equation (10) becomes $dH = dQ + V.dp$ (11)

In biological processes $dp = 0$, equation (11) becomes $dH = dQ$, which means that the enthalpy change is measured by the isobaric thermal effect of the process.

The amount of isobaric heat (enthalpy change) obtained by burning various biochemical substances is about the same for amino acids, proteins and carbohydrates, but it is about 3 times higher for lipids, which explains the function of fat energy reserves in the body.

The state parameter that measures the real ability of a system to work at constant pressure is **the free enthalpy G defined by the equation:**

$$\mathbf{G = H - TS} \qquad (12)$$

This thermodynamic parameter shows how much of a system's internal energy can be converted into mechanical work at constant pressure,**G is also called Gibbs free energy.**

In biological processes that are isobaric, the possibility of obtaining any form of mechanical, osmotic, electrical work is expressed by the variation of free enthalpy during the process.

The thermodynamic parameters defined here are:

Internal energy (U)
Free energy (F)
Enthalpy (H)
Free enthalpy (G)
Entropy (S)

That are physical quantities widely used to characterize the states and transformations of any system, including biological and ecological systems.

THE SECOND PRINCIPLE of thermodynamics states that by any process that occurs in an isolated system, its energy and free entropy F and its entropy S increase.

If the process is quasi-static or irreversible, the system can be restored to its initial state in the external environment without change, and the system has received the amount of heat dQrev maintained at a constant temperature T, then the entropy of the system increases by: $dS = [(dQrev) / T]$ (13)

If the process is non-static or irreversible (the system cannot be restored to its original state without changes in the environment to produce changes) the heat and some of the free energy of the system.

If the process is non-static or irreversible, the system cannot be returned to the initial state without changing the environment and the system has received the amount of heat dQrev, with the maintenance of the temperature T, the entropy of the system increases by: $dS > [(dQrev) / T]$

(14)

The entropy of the system increases as a result of any process only if the system is isolated. This is the statement of the second law of classical thermodynamics, which studied only isolated systems.

In open systems, such as living organisms, entropy can even be low, with the condition that it increases in the environment.

If a living organism is assigned a limited environment, the whole organism-environment can be considered as a system isolated from the rest of the environment, and the second principle of thermodynamics can be applied to the isolated system.

The concept of entropy was introduced in 1865 by Clausius. The physical meaning of the concept of entropy was introduced by Boltzmann who linked this concept to the internal structure of the system (molecular or atomic).

A system is known to be in one of the macroscopic states, although some component parts (molecules or atoms) are arranged differently from each other.

If N indicates the number of arrangements of the parts of a system, corresponding to a macroscopic state of the system, and S the thermodynamic entropy of the system in this state, then, according to **relationship established by Boltzmann:** $S = k.\ln N$ **(15)**

where k is Boltzmann's constant $k = 1.38.10^{-23}$ J/K.

where the entropy S of the system is directly proportional to the natural logarithm of the number N of arrangements of the system's component parts.

If the order of the system increases, the number of bonds between the molecules of the system also increases. As a result, the molecules can arrange themselves in fewer configurations and therefore the value of N decreases, which also decreases the entropy S of the system. If the increasing order of the system is a means of decreasing the entropy of the system, on the contrary, a perturbation of the system will allow a greater number of arrangements of the molecules, which means an increase in entropy.

In conclusion, we can say that the second law of thermodynamics is a general law of nature that states that:

All processes that take place in isolated systems go in the direction of increasing the entropy of these systems, that means, in the direction of decreasing their degree of organization. The course of these processes takes place in the direction of decreasing the ability of the system to perform mechanical work (decreasing free energy).

According to this principle, for an isolated system, a decrease in entropy is considered an extremely improbable phenomenon.

The physical interpretation of the second law of thermodynamics is that entropy decreases and the order of systems would either remain constant or increase.

In living organisms, foods with a relatively low energy state are transformed into substances with higher energy content and more ordered structural state. This contradicts the second law of thermodynamics at first sight.

After formulating the principle of entropy increase, considered valid for all processes, it was noted the diametrically opposite behavior of organisms and the living world as a whole, whose evolution goes in the direction of increasing structural complexity and diversifying functions, thus reducing entropy.

THE SECOND PRINCIPLE OF THERMODYNAMICS does not correctly describe the situation of living organisms that, during at least part of their life, develop and complicate their structure by synthesizing complex macromolecules by organizing them into a well-defined supramolecular architecture.

The SECOND PRINCIPLE OF THERMODYNAMICS in its classical form applies only to isolated systems (without exchange of substance with the environment), while biological systems are open systems, so the SECOND PRINCIPLE OF THERMODYNAMICS in its classical form cannot be applied to biological systems.

E. Schrödinger showed that the principles of thermodynamics were formulated before biological systems were studied in depth. Therefore, Schrödinger advises caution in applying the principles of thermodynamics to living organisms that are open systems in which irreversible processes also occur.

In a system without exchange of substances with the environment, the processes that take place in it are limited by the number of substances available in the system that can enter into mutual reactions, and when the reaction is complete, there is an equilibrium state, characterized by the time constancy of the system properties. The thermodynamic conditions of this thermodynamic equilibrium result from the minimum free energy of the system and the maximum value of entropy.

In an open system, there is a continuous flow of substances in and out.

Instead of the thermodynamic equilibrium of the system characterized by the rate of chemical reactions and diffusion which must be constant.

Thermodynamic equilibrium and steady state are similar in that the system permanently maintains its properties.

In a state of thermodynamic equilibrium there is no change in free energy, when the steady state free energy varies at a constant rate, i.e.:

$$(dF) / (dT) = 0$$

An unlimited number of steady states can exist for a living organism, depending on the internal and external conditions of the system.

In the steady state of an open system, the entropy remains constant, but its value differs from the maximum value.

The steady or steady state is maintained because the system continuously receives free energy from the environment, i.e., an amount that compensates for the free energy variation of the system at the boundary.

For a system that has no exchange of substance with the environment in the case of thermal equilibrium, the entropy remains constant over time, i.e. its variation over time is zero: $(dS) /dt=0$

For an open system, entropy generally increases with time, namely:

$$(dS) / dT > 0$$

But the entropy of open systems can also decrease if they produce entropy to the external environment.

Prigogine's formula for the variation per unit time of the entropy of an open system is the following:

$$[(dS) / dt] = [(dSi) / dt] + [(dSe) / dt]$$

Or

- **[(dSi)/dt] is the entropy change per unit time resulting from system changes** (in irreversible processes)
- **[(dSe)/dt] is the entropy change per unit time resulting from the system's interaction with the outside.** The magnitude can be positive or negative. It is negative because of the import of external negative entropy, which is equivalent to the situation where the system gives entropy to the environment.

If [(dSE) / dt] exceeds in absolute value the term [(dSI) / dt] then the entropy of the system decreases.

In the famous formulation Schrödinger indicated: living organisms "avoid" increasing their entropy by taking negative entropy from the external environment. This means that organisms receive free external energy, either as radiant energy if plants are photosynthesizing, or as chemical energy stored in animal feed, and ecosystems remove waste from additional metabolic activity (breakdown products and heat).

According to Schrodinger's theory, animals feed on negative energy.

Substances taken externally, such as glucose (S = 50.7 kcal/mol.K) and oxygen (S = 48.9 kcal/mol.K) have lower entropy than substances resulting from the oxidation of organic substances: CO_2 (S = 49.0 kcal/mol.K) and water (51.1 kcal/mol.K). Thus, the entropy of an open system can not only increase, but also decrease.

The decrease in entropy is very slow and is believed to be because the energy released in metabolic processes is consumed by biological systems.

The decrease in entropy during the evolution of an organism results in a greater degree of organization in that organism due to the import of external matter and energy from negative entropy.

There may be processes, some of which are accompanied by a decrease in entropy, and others by its increase, so that the total variation of entropy in said space is positive. Such coupling is found in many irreversible processes that occur in the living and inanimate worlds.

Recent research shows that the energy production pathway in tumor cells is altered. In the normal cell, the aerobic energy production process predominates, which has a higher efficiency.

Anaerobic glycolysis predominates in tumor cells, the yield of which is low.

The energetics of tumor cells resemble the energetics of embryonic cells. Alteration of cellular energy under pathological conditions remains to be studied in the future.

The thermodynamics of irreversible processes includes so far only small deviations from thermodynamic equilibrium.

Open systems theory is applied to adaptation phenomena and to many problems in the physiology and biochemistry of microorganisms.

The thermodynamics of open systems provides new perspectives for biophysics to examine biological systems.

It is predicted that many inexplicable phenomena will find the correct explanation, with the development of biological thermodynamics in the study of biological systems:

- the unification of the principles of thermodynamics with information theory;
- drug interactions with biological systems;
- the influence of physical environmental factors on biological systems;
- growth, aging and malignant pathology phenomena.

CALCULATION OF MECHANICAL WORK, HEAT AND ENERGY CHANGE IN SIMPLE THERMODYNAMIC PROCESSES

GENERAL CASE

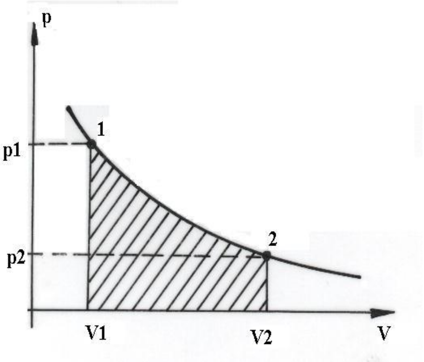
Work in thermodynamics is calculated using the formula: $W_{12} = \int_{V1}^{V2} p.dV = A_{12V2V1}$

p- is the pressure of the gas under consideration;

dV is the elementary volume variation;

W_{12} is work from 1 to 2

A_{12v2v1} is the area formed by the pressure curve of 1-2, the descending perpendiculars from the initial state to the final state on the axis of the two volumes.



When p=const we have: $W_{12} = p.\Delta V = p(V_2 - V_1) = A_{12V2V1}$

Internal energy variation : $\Delta U = \nu\, C_V \Delta T$

ν is the amount of substance;

C_V is the molar isochore heat;

ΔT is the change in temperature from the initial state to the final state

This form of expression is valid for any type of transformation.

heat: Q= ΔU+W

POLYTROPIC TRANSFORMATION: p · V^n = const

THE WORK

In a polytropic transformation, the volume of the ideal gas varies from V1 to V2,

The work done by an ideal gas is

$$W_{1-2} = \int_{V_1}^{V_2} pdV = p_1V_1^n \int_{V_1}^{V_2} \frac{dV}{V^n} = \frac{p_1V^n{}_1}{n-1}\left[V^{-n+1}\right]_{V1}^{V2}$$

Or: $$W_{1-2} = \frac{p_1V^n{}_1}{n-1}\left(V_2^{1-n} - V_1^{1-n}\right) = \frac{1}{n-1}\left[p_2V_2^{1-n}V_2^n - p_1V_1^{1-n}V_1^n\right] = \frac{1}{n-1}\left[P_2V_2 - p_1V_1\right]$$

Or:

$$W_{1-2} = \frac{1}{n-1}\left(p_2V_2 - p_1V_1\right) = \frac{\nu.R}{n-1}\left(T_2 - T_1\right)$$

Variation of internal energy $\Delta U = \nu\, C_V \Delta T$

Heat received or given from ideal gases during the polytropic process.

If c_v and c_p are the molar specific heats then

$$Q_{1-2} = U_2 - U_1 + W_{1-2} = vc_v\left(T_2 - T_1\right) + \frac{vR}{n-1}\left(T_2 - T_1\right)$$

Or:

$$Q_{1-2} = vc_v\left(T_2 - T_1\right) + \frac{v\left(c_p - c_v\right)}{n-1}\left(T_2 - T_1\right) = vc_v\,\frac{n-\gamma}{n-1}\left(T_2 - T_1\right)$$

ADIABATIC TRANSFORMATION: pV^{γ}= const.

In an adiabatic transformation dQ = 0 (**no heat exchange with the exterior**) has the polytropic coefficient of the form n = γ, so the work has the following form: $W_{1-2} = \frac{vR}{\gamma - 1}\left(T_1 - T_2\right)$

From the coupling relations between isochoric, isobaric molar heat and the universal gas constant R: $C_p - C_v = vR$;

$\frac{C_p}{C_v} = \gamma$ Adiabatic coefficient

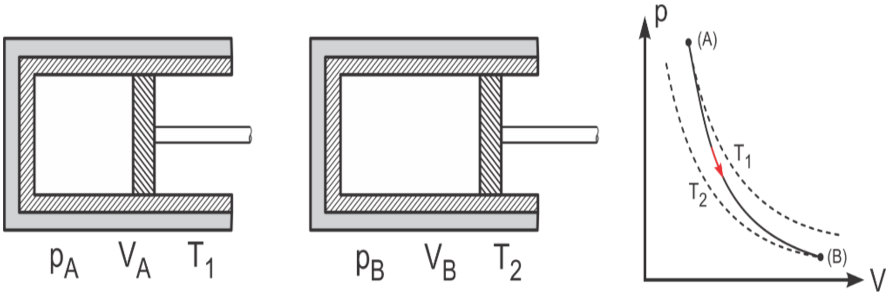
W1-2 = c_v (T1-T2) = U1-U2 = - Δ U

In adiabatic processes **the work** done is the result of the decrease in the heat of ideal gases :

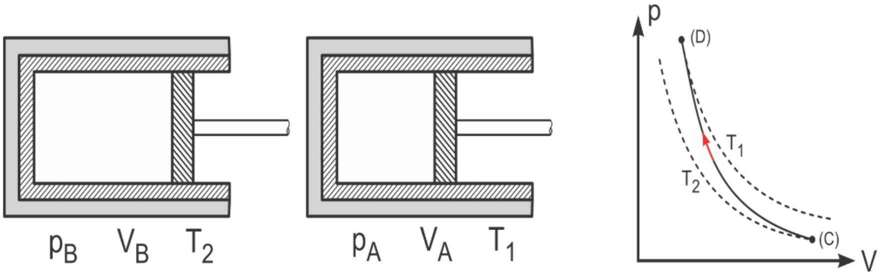
$$W_{1-2} = \frac{vR}{\gamma - 1}\left(T_1 - T_2\right)$$

The change in internal energy is: $\Delta U = v\, C_V \Delta T$

Heat is Q=0



During adiabatic expansion the temperature of the ideal gas decreases



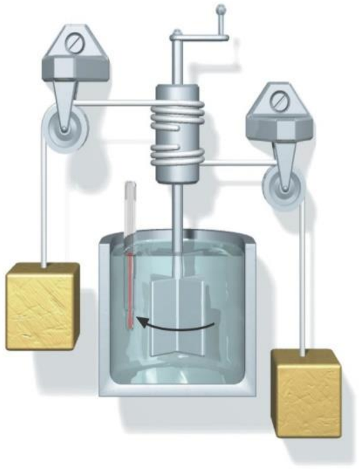
During adiabatic compression, the ideal gas temperature increases

SD Poisson (1781 – 1840)

In practice, it is impossible to achieve a perfect adiabatic transformation (it is impossible to eliminate perfect heat exchange with the medium) and it is also difficult to achieve a perfect isothermal transformation.

In practice, the transformations are "polytropic" (transformations intermediate between isothermal and adiabatic transformations). The equation of a polytropic transformation from the initial state "1" to the final state "2") is: $p_1 \cdot V_1^n = p_2 \cdot V_2^n = const.$ $(1 \le n \le \gamma)$

THE MECHANICAL EQUIVALENT OF HEAT

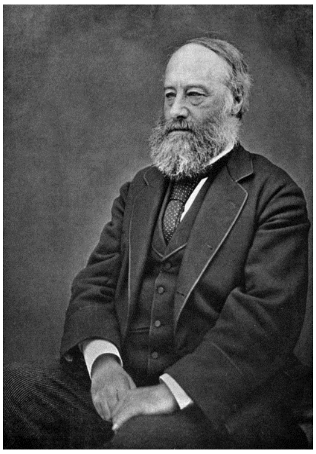


The expression of Amount of heat: cal & kcal introduced by Nicolas Clément

1 cal ("gram calorie") is the amount of heat required to raise the temperature of one gram of water from 4.5°C to 5.5°C

1 kcal (calories ("large" calories or ("kilogram calorie")) is the amount of heat required to raise the temperature of one kilogram of water from 5.5°C to 4.5°C

The amount of heat is a form of energy – To prove and determine the equivalence we establish **1 cal = 4.18400 J**



James Prescott Joule (1818-1889) Julius Robert von Mayer (1814-1878)

SPECIAL CASE: EXTERNAL TRANSFORMATION (T=const.)

isothermal transformation n = 1 (pV = const.)

T=const. and ΔT=0

The isothermal transformation equation is PV = const = P1V1 = P2V2

THE WORK

It is calculated by the formula

And replace

THE WORK

Variation of internal energy: $\boldsymbol{\Delta U = 0}$

(ΔU = ν · Cv · ΔT – general formula)

Since ΔT = 0 – due to constant temperature, there is no temperature variation

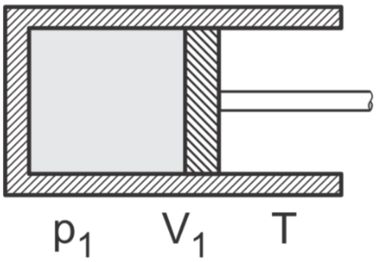
Heat: obtained here from the first principle of thermodynamics:

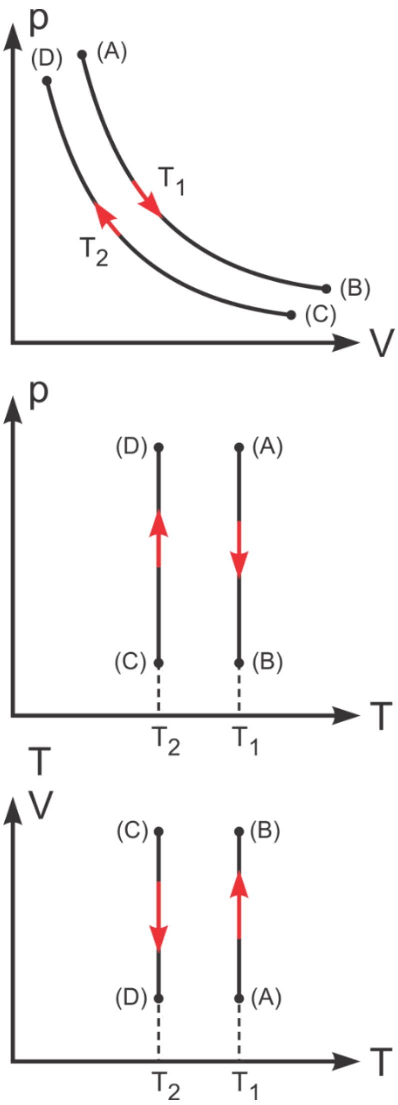
Q = Δ U + W

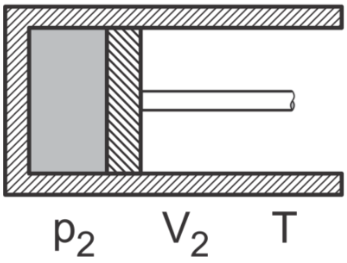
Since the change in internal energy is zero, heat equals work: Q = W

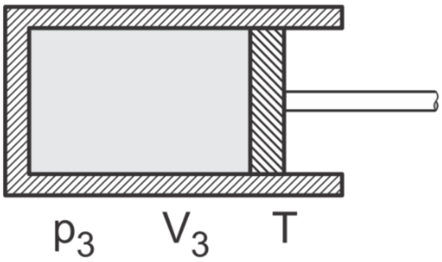
ISOTHERM TRANSFORMATION (T=CONST.)

BOYLE-MARIOTTE LAW









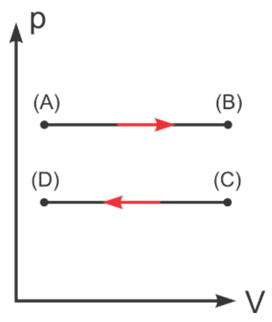
(A) →(B) Isothermal expansion (T_1)

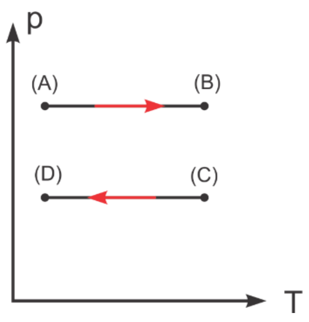
(C) →(D) Isothermal compression (T_2)

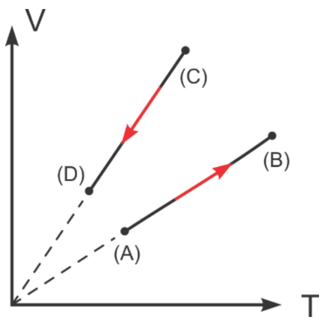
$T_1 > T_2$

Boyle-Mariotte Law: $p_A \cdot V_A = p_B \cdot V_B$

ISOBARIC TRANSFORMATION (P=CONST) – CHARLES'S LAW







(A) →(B) Isobaric heating $\frac{V_A}{T_A} = \frac{V_B}{T_B}$

(C) →(D) Isobaric cooling $\frac{V_C}{T_C} = \frac{V_D}{T_D}$

The thermal equation of ideal gases: $pV= \upsilon RT$

(*Mendeleev-Clapeyron*)

General transformation

$(p_A , V_A , T_A) \rightarrow (p_B , V_B , T_B)$ for the ideal gas

$$\frac{p_A \cdot V_A}{T_A} = \frac{p_B \cdot V_B}{T_B}$$

R: universal ideal gas constant (*H.V. Regnault*)

$R = 8.3144$ J-mol $^{-1}$ -K $^{-1}$; $R = 0.08205$ l•atm•K $^{-1}$ •mol $^{-1}$

ISOBARIC TRANSFORMATION – in this case we assume that **p= const**

So $p2 = p1$ and $n = 0$

The work is: **$W_{1\text{-}2} = p1\,(V2-V1) = \upsilon R\,(T2-T1)$**

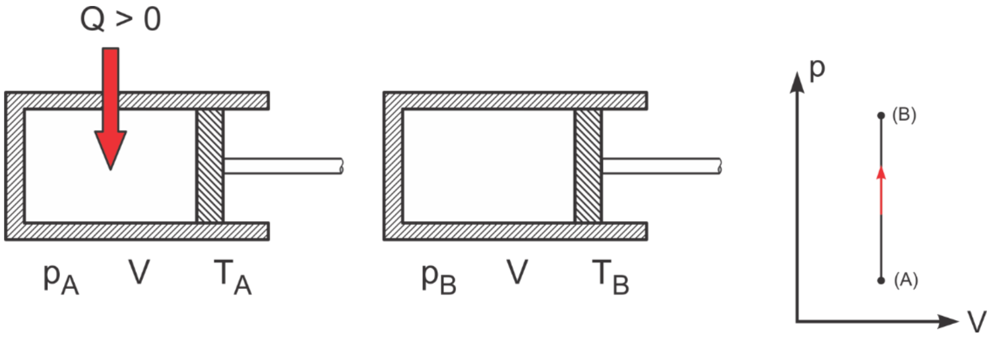
The change in internal energy is: $\Delta U = \upsilon C_V\, \Delta T$

Heat is obtained here from the first law of thermodynamics:

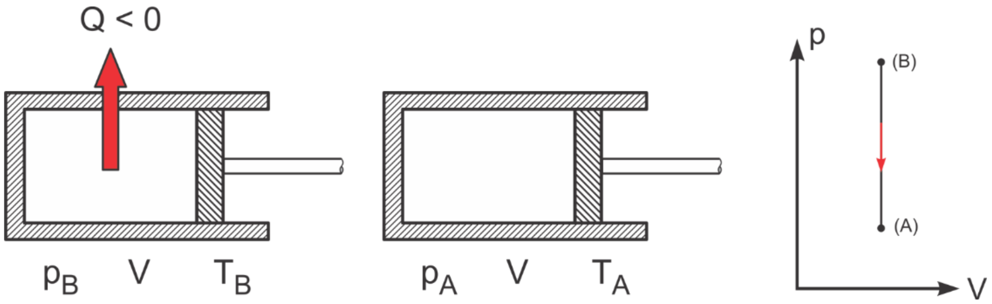
$Q= \Delta U + W = \upsilon C_V\, \Delta T+ \upsilon R\, \Delta T = \upsilon Cp\, \Delta T$

ISOCHORIC TRANSFORMATION (V=const):

Gay-Lussac's law



In an isochoric heater the gas picks up heat from the surroundings and increases the pressure of the gas



In an isochoric cooling, the gas gives off heat to the environment and reduces the pressure of the gas

$$\frac{p_A}{T_A} = \frac{p_B}{T_B}$$

For the isochore TRANSFORMATION we assume that n = ±∞

For isochoric TRANSFORMATION it is assumed that V=const.

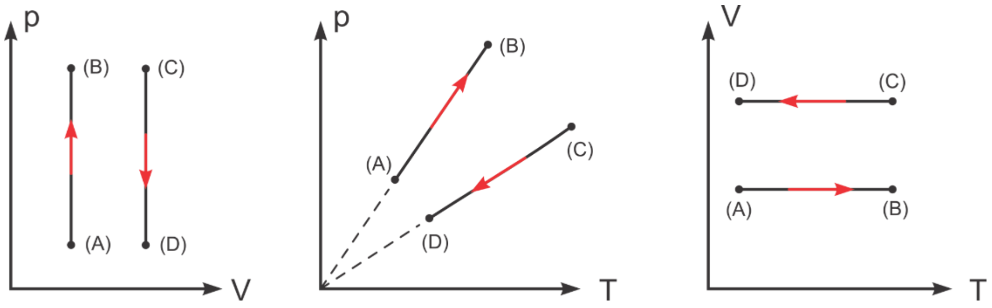
The work is W1-2 = 0 ($W = p \cdot \Delta V$ and V = const, $\Delta V = 0$)

Because the volume of initial state 1 coincides with that of final state 2

Internal energy change: $\Delta U = \upsilon C_V \Delta T$

Heat: we get it here from the first law of thermodynamics:

$Q = \Delta U + W = \upsilon C_V \Delta T$



(A) →(B) isochoric heating $\frac{p_A}{T_A} = \frac{p_B}{T_B}$

(C) →(D) isochoric cooling $\frac{p_C}{T_C} = \frac{p_D}{T_D}$

In an isochoric transformation the ideal gas does not realize mechanical work on the medium and the ideal medium does not realize mechanical work on the ideal gas (W = 0).

For $1 < n < \gamma$, the specific heat c_n is negative.

In this transformation, the expanding gas does more mechanical work than the heat provided by the gas.

To perform mechanical work, the gas consumes some internal energy.

Thus, for the polytropic index n between 1 and γ a particular transformation takes place and the gas cools, but has received heat from the outside.

- For diatomic gases: Cv = 5/2R and Cp = 7/2R

- For monatomic gases: Cv = 3/2R and Cp = 5/2R

THERMODYNAMIC POTENTIAL CALCULATION

ENTROPY S

Experiments performed with the same thermodynamic system, for example an ideal gas, show that:

The isotherms do not intersect;

Adiabats do not intersect;

An adiabatic isotherm and an adequate isotherm intersect at only one point in the (V, p) plane.

All these experimental results show that there is an unequivocal relationship between the parameter pairs (S, T) and (p, V).

Namely, a pair of values p1, V1 corresponds to a single pair of values S1, T1.

Therefore, for all thermodynamic systems, we obtain the clear dependencies:

- P=P(T,S);
- V=V(T,S);

Absolute entropy of ideal gas

Relation between elemental heat and entropy change

From the previous discussion it follows that there is a proportional relationship between elementary heat and entropy change: dS= δ Q/ α Or $\frac{dQ}{dS} = T$

where α is an essential factor that transforms the elementary value δQ into an exact total differential dS.

Definition of entropy : $\frac{dQ}{T} = dS$

Entropy formulas for different thermodynamic processes

- **for the isobaric process** $dQ_p = \nu . c_p . dT$; $dS_p = \nu c_p \frac{dT}{T}$
- **for the isochoric process** $dQ_v = \nu . c_v . dT$; $dS_v = \nu c_v \frac{dT}{T}$
- **for the isothermal process** $dQ_T = \nu RT \frac{dV}{V}$; $dS_T = \nu R \frac{dV}{V}$
- **for the adiabatic process** $\delta Q = 0$; dS = 0

THE FUNDAMENTAL EQUATION OF THERMODYNAMICS

Thus it appears that: $Q_{1-2} = \int_{S1}^{S2} TdS. \quad ou \quad dQ = T.dS$

the fundamental equation of the thermodynamics of quasi-static and reversible processes: dU = dQ - dW

dU = T.dS-p.dV

In geometric terms, heat has the same signification in [S, T] as work has in [V, p].

PROPERTIES OF ABSOLUTE ENTROPY

The absolute entropy S is a state function and dS is an exact total differential and: $\oint dS = 0$

In adiabatic and quasi-static processes, absolute entropy is conserved [S = constant, dS = 0]

The absolute entropy is a function of additive states, i.e. for several subsystems we obtain: $S = \sum_{k=1}^{N} S_k$

Entropy is defined up to an arbitrary additive constant S_0, which cannot be determined by the second law of thermodynamics.

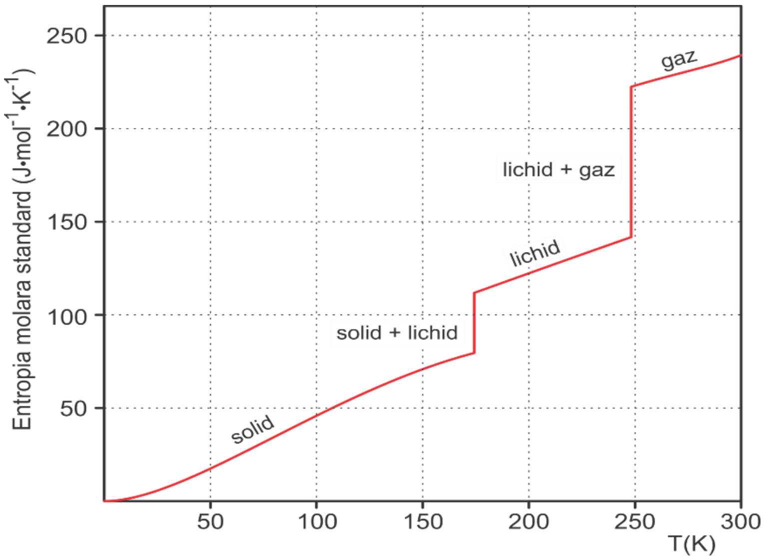
However, **the entropy variation between two states is well defined** $S_2 - S_1 = \int_1^2 \frac{\delta Q}{T}$

Thermodynamic potentials are introduced similarly to potential energy in mechanics $\delta W = F\,dx = -dE_P$

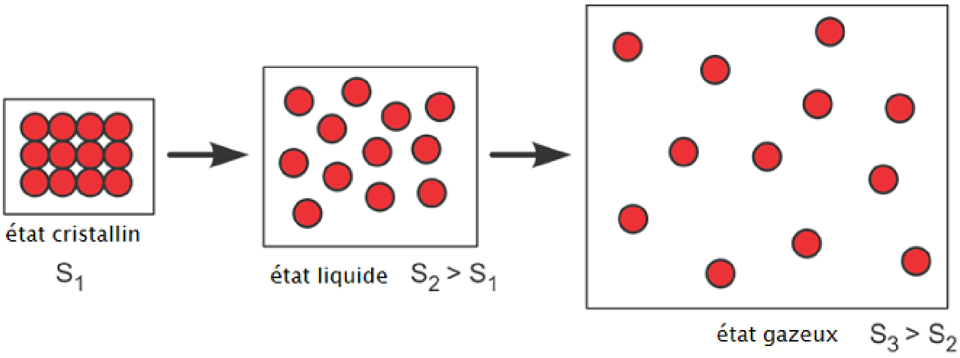
If the potential energy is minimal, the system is in stable equilibrium.

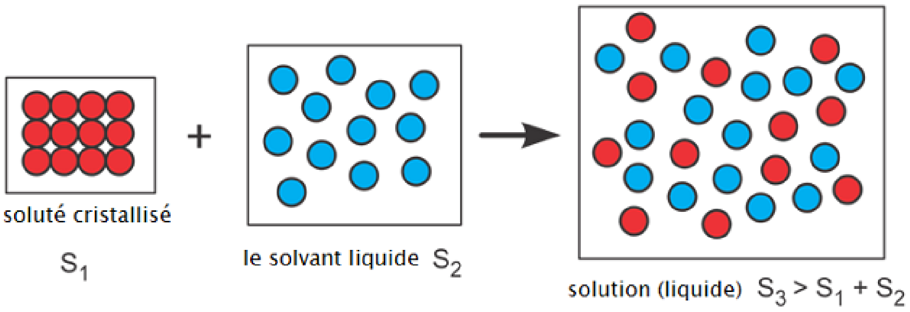
Similarly, thermodynamic potentials satisfy the requirements: their derivative with respect to a generalized coordinate is a generalized force.

When the thermodynamic potential is minimum, the system is in a state of thermodynamic equilibrium.



Entropy variation during phase transformations





The entropy of a thermodynamic system correlates with the degree of "disorder" (number of degrees of freedom) internal to the system

INTERNAL ENERGY U

- The fundamental equation of the thermodynamics of the process is:
- $dU = dQ-p.dV = T.dS-p.dV$
- where the internal energy U is a function of the states of the thermodynamic variables S and V: $U = U(S, V)$
- $dU = \left(\frac{\partial U}{\partial S}\right)_v dS + \left(\frac{\partial U}{\partial V}\right)_s dV$

Thus it can be written

$$T = \left(\frac{\partial U}{\partial S}\right)_v ;$$

$$p = \left(\frac{\partial U}{\partial V}\right)_s$$

FREE ENERGY F

The free energy F is defined by the equation: $F = U - T\cdot S$

If within the considered system the volume V and the absolute temperature T vary, the following formula can be written:

$dF = dU- (TdS+SdT) = (T.dS-p.dV)- (TdS+SdT) =$

$dF = – S.dT -p.dV$

meaning that, the free energy F is a function of the variables V and T:

$F=F(T,V)$

$$dF = \left(\frac{\partial F}{\partial T}\right)_v dT + \left(\frac{\partial F}{\partial V}\right)_T dV$$

Or:

$$S = -\left(\frac{\partial F}{\partial T}\right)_V$$

$$p = -\left(\frac{\partial F}{\partial V}\right)_T$$

This is the first Gibbs-Helmholtz relation.

Free energy is the part of the internal energy that the system can change with the environment, and the amount of energy **E1 = TS is called bound energy**, because it cannot be removed from the system.

In **isothermal processes: $dF= -p.dV= - dW$**

$$W = -\int_1^2 dF = F_1 - F_2$$

It follows that the decrease in free energy represents the work done by the thermodynamic system of isothermal processes.

ENTHALPY H

Enthalpy H is defined by the equation: H = U + pV

From which we can obtain: dH = dU + p.dV + V.dV

If within the considered system pressure and entropy vary, the expression of enthalpy H can be written as follows: **dH = T.dS + V.dp**

When **H = H (S, P)** $dH = \left(\frac{\partial H}{\partial S}\right)_p dS + \left(\frac{\partial H}{\partial p}\right)_S dS$

$$T = \left(\frac{\partial H}{\partial S}\right)_p$$

And

$$V = \left(\frac{\partial H}{\partial p}\right)_S$$

If the thermodynamic process is isobaric (p = const) then: **dH = T.dS = dQ**

The enthalpy variation in thermodynamic processes represents the isobaric heat received or given by the system.

We can write the relation: U = Hp.V

$$U = H - pV = H - p\left(\frac{\partial H}{\partial p}\right)_S$$

FREE ENTHALPY G

The free enthalpy of the thermodynamic function G is given by the expression

G = H-TS= U+ pV-TS

In systems where there are pressure and temperature ranges, the formula of the variation of the free enthalpy can be written as follows:

dG = + V.dp-S.dT

where G = G (p,T) then $dG = \left(\frac{\partial G}{\partial p}\right)_T dp + \left(\frac{\partial G}{\partial T}\right)_p dT$

$$V = \left(\frac{\partial G}{\partial p}\right)$$

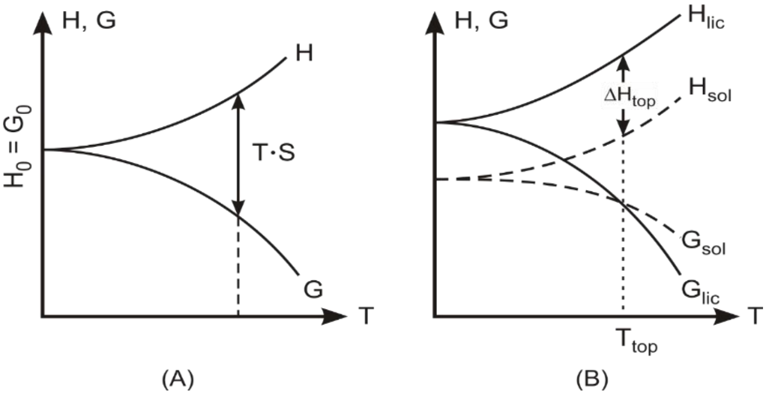
And

$$S = -\left(\frac{\partial G}{\partial T}\right)_p$$

Enthalpy H can be expressed in terms of free enthalpy

$$H = G + TS = G - T\left(\frac{\partial G}{\partial T}\right)_p$$

This is the second Gibbs-Helmholtz relation

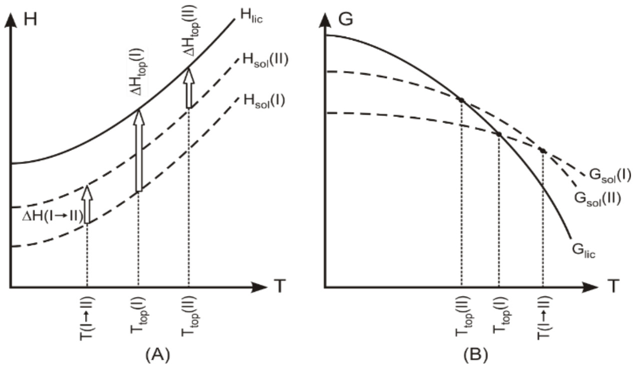


Variation of enthalpy and free enthalpy with temperature

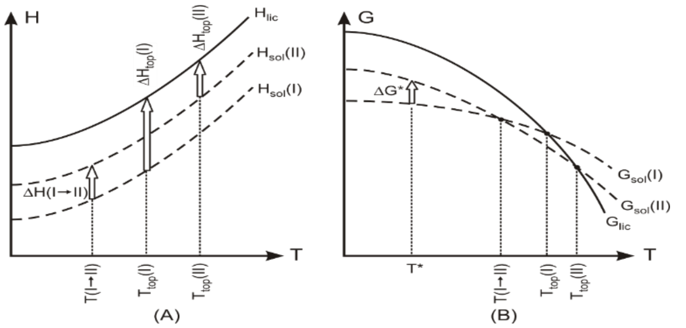
Variation of Gibbs enthalpy H and free enthalpy G as a function of temperature.

(A) in the case of a homogeneous phase

(B) in the case of a heterogeneous solid-liquid phase



Variation of enthalpy H (A) and Gibbs free enthalpy G (B) as a function of temperature - in the case of a heterogeneous solid-liquid separation phase with monotropic polymorphism



Variation of enthalpy (A) and free Gibbs enthalpy (B) as a function of temperature in the case of a heterogeneous solid-liquid separation phase with enantiotropic polymorphism

$\Delta G^* = R \cdot T^* \cdot \ln \frac{S^*(II)}{S^*(I)}$ or S* - solubility at temperature T*

APPLICATIONS OF THE SECOND PRINCIPLE OF THERMODYNAMIC CYCLES AND HEAT ENGINE

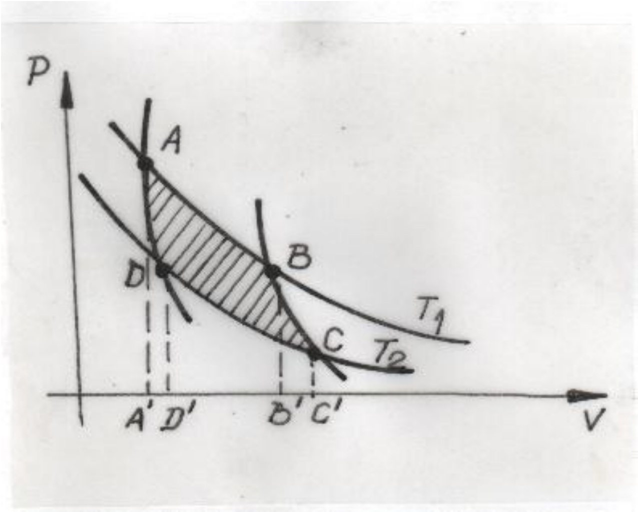
CARNOT CYCLE. CARNOT'S THEOREM

According to Kelvin's postulate, it is not possible for a monothermal engine to exist.

We then try to build a bithermal engine which is an engine using the temperatures $T1 \neq T2$ of the two heat sources. In addition to the two heat sources, we will also need a third body called the work body. Such a system that will come into contact with two heat sources will have to transform the amount of heat into mechanical work without producing other changes in the system which performs the transformation.

French engineer Sadi Carnot tackled this problem and in 1824 proposed the cyclic process that bears his name.

CARNOT CYCLE



The figure gives the Carnot plot

A →B - the gas expands the isotherm

It absorbs heat from a hot source: $Q_{AB} = Q_1 > 0$

B →C - adiabatic expansion which depends of the internal energy of the gas

At point C, the system comes into contact with the cold source of T_2 and due to the mechanical work transferred to the external environment, the gas will compress isothermally from **C to D.**

C →D - isothermal compression

D →A - adiabatic compression

$Q_{DA} = 0$

After the execution completes the cycle according to the first law of thermodynamics it follows that

W = Q1 - Q2

W = mechanical work for the complete cycle

As a result, mechanical work was produced throughout the entire cycle. As a result, it works like an engine.

It can be shown that any motorcycle (reversible or irreversible) operating between temperatures T_1 and T_2 can produce work only if the source absorbs heat from the hot source and releases heat from the hotter source to the cooler source, but not vice versa.

Going through the resulting cycle in a reverse manner it follows that

-W = -Q1+Q2 + thus, a refrigerator device.

CALCULATE THE EFFICIENCY OF THE CARNOT CYCLE

By definition, the efficiency of a thermal cycle is: $\eta = \frac{W}{Q_1}$

W = work done in one cycle

Q1 = heat absorbed by the hot source

$$\eta = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{|Q_2|}{Q_1} < 1$$

AB - isothermal transformation: $Q_1 = R \cdot T_1 \cdot \ln \frac{V_B}{V_A}$

CD - isothermal transformation: $Q_2 = R \cdot T_2 \ln \frac{V_C}{V_D}$

Therefore, we can write the efficiency of the Carnot cycle as: $\eta = 1 - \frac{R \cdot T_2 \cdot \ln \frac{V_C}{V_D}}{R \cdot T_1 \cdot \ln \frac{V_B}{V_A}}$

Taking into account the adiabatic transformation from B to C and from D to A, it follows that: T2 < T1

The performance of the Carnot cycle will have the following form: $\eta = 1 - \frac{T_2}{T_1}$

$$T_1 \cdot V_B^{\gamma-1} = T_2 \cdot V_C^{\gamma-1}$$

$$T_2 \cdot V_D^{\gamma-1} = T_1 \cdot V_A^{\gamma-1}$$

$$\frac{T_1 \cdot V_B^{\gamma-1}}{T_1 \cdot V_A^{\gamma-1}} = \frac{T_2 \cdot V_C^{\gamma-1}}{T_2 \cdot V_D^{\gamma-1}} \frac{T_1 \cdot V_B^{\gamma-1}}{T_1 \cdot V_A^{\gamma-1}} = \frac{T_2 \cdot V_C^{\gamma-1}}{T_2 \cdot V_D^{\gamma-1}}$$

The performance of the Carnot cycle has the following form:

$$\eta = 1 - \frac{T_2}{T_1}$$

CARNOT'S THEOREM

Among the many engines that operate between the same temperatures T1 and T2, not all engines have the same η, while irreversible engines have one η that never exceeds the η reversible engine .

$$\eta(irev) = 1 - \frac{Q_1}{Q_2} \quad et \quad \eta(rev) = 1 - \frac{Q_1^{'}}{Q_2^{'}} \quad et \quad \eta(irev) = \eta(rev)$$

The efficiency of a heat engine operating according to the Carnot cycle is

$$\eta_c = \frac{W}{Q_1} = \frac{Q_1 - |Q_2|}{Q_1} = \frac{T_1 - T_2}{T_1}$$

It can be shown quite simply that the efficiency of the Carnot cycle does not depend on the nature of the organism.

Also, the Clausius equality holds for an arbitrary quasi-static cycle, given that any cycle can be approximated by a sequence of isotherms and adiabats.

If $T_1 = T$, $Q_1 = Q$ and $T_2 = T_0$ and $Q_2 = Q_0$

we can write: $\frac{Q}{T} = \frac{Q_0}{T_0} \quad T = T_0 \frac{Q}{Q_0}$

It is obvious that in this expression the heat Q and Q_0 play the role of a thermometric property independent of the thermodynamic system. If T_0 defines the reference temperature, T is the absolute temperature because T does not depend on the thermodynamic system used.

By convention, the reference isotherm was established, corresponding to the triple point of water, where $T_0 = 273.16$ K. It should be noted that this relationship defines the absolute zero point.

For Q = 0 one can obtain T = 0, which means that the absolute zero isotherm merges with the adiabatic one. This is the basic difference between empirical temperature scale and absolute temperature scale.

In all empirical temperature scales θ, the point temperature θ0 = 0 is not unambiguously defined. Since the temperature point T = 0 K, we have Q = 0. This proves that the temperature T = 0 K has a special physical meaning.

The cooling of bodies to a temperature below the ambient temperature outside is achieved by refrigeration, operating on completed counterclockwise cycles.

For these installations we have the following relations: W= │Q1│- Q2

The characteristic of a refrigeration installation is given by the ratio between the refrigeration effect:

$$\varepsilon = \frac{Q_2}{W} = \frac{Q_2}{|Q_1| - Q_2}$$

If η is the efficiency of the clockwise cycle, then: W = η.│Q1│, Q2= │Q1│(1- η), ε= Q2/W=Q2/[│Q1│-Q2] = (1/η) -1

Efficient heat pumps are characterized by: K= │Q1│/W=1/η

For refrigeration systems operating on an inverted Carnot cycle, we obtain: ε=T2/[T1-T2] , if K = T1/[T1-T2]

OTTO ENGINE

Engines running on the four-stroke cycle invented by Nikolaus Otto in 1876 involve a four-stroke cycle and an internal combustion engine.

It is the most used cycle in the automotive industry today.

A 4-stroke cycle is more efficient than a 2-stroke cycle, even though more moving parts are required.

The 4-stroke Otto cycle runs from 30rpm to 1000rpm to reach the 6000rpm limit respectively

Intake: The cycle begins at top dead center, when the piston is at its highest point. During the first stroke the piston descends (intake), a mixture of air and fuel from the carburetor or injection is sucked into the cylinder through the intake valve.

Compression: The intake valve closes, the piston rises, compressing the intake mixture.

Combustion-expansion: The air-fuel mixture is then ignited, usually by a spark plug, around second top dead center (full piston extension). The pressure of the high-temperature gases produces an explosion during combustion and forces the piston down for the third stroke (combustion-expansion). This movement is the only driving time (producing directly usable energy).

Exhaust: During the fourth and final stroke, the exhaust valve opens to expel the burnt gases pushed by the lift of the piston.


Point mort haut, départ


1 - admission

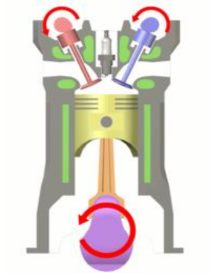

2 - compression

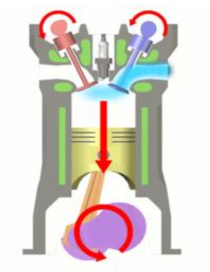

Le carburant est enflammé

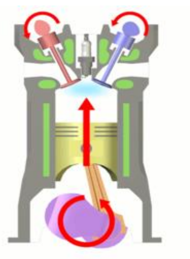

3 - détente

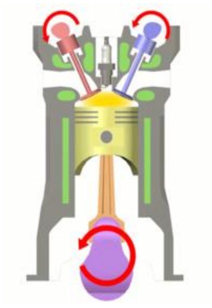

4 - échappement

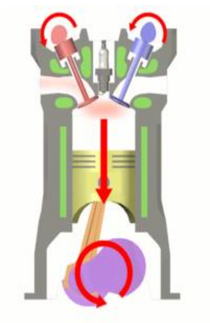
OTTO CYCLE - DURATION

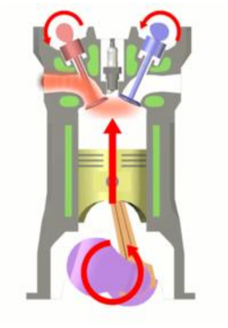

Starting positions


admission

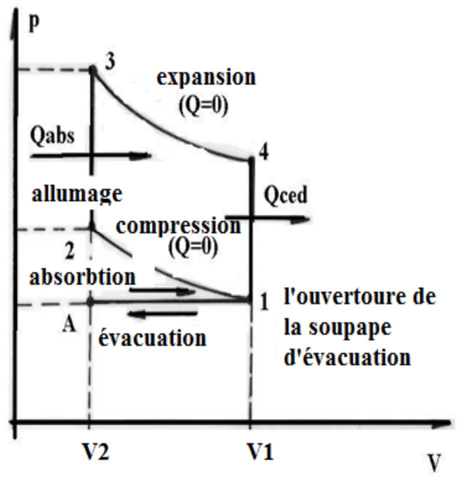

compression







Fuel ignition combustion trigger exhaust



This cycle is characterized by four strokes or linear movements of the piston:

Admission : A →1 , p1 = const.

(Absorption) : (isobaric process)

Compression : 1 →2 , Q=0: (adiabatic transformation)

Combustion-Expansion: 2 →3: V2 = const

3 →4: Q=0

4 →1: V1=const

Exhaust : 1A →, p1=const

If we note ε= V1/V2 - compression ratio where adiabatic coefficient

OTTO ENGINE PERFORMANCE CALCULATION:

The output of the Otto cycle then has the expression: $\eta = 1 - \varepsilon^{1-\gamma}$

where γ is the adiabatic coefficient.

The general formula for calculating the efficiency of a heat engine is the following: $\eta = 1 - \frac{|Q_{rel}|}{Q_{abs}}$

Where Q_{rel} is the residual heat, $Q_{rel} < 0$

And Q_{abs} is the absorbed heat, it is always: $Q_{abs} > 0$

1-2: adiabatic transformation:

Q12 = 0 there is no heat exchange outside

2-3: isochoric transformation:

V_2=const → dV=0 →W_{23}=0

$Q_{23} = \upsilon.Cv\ (T_3 - T_2) > 0 \rightarrow Qabs = Q_{23}$

Since the temperature in state 3 is higher than in state 2, we can conclude that from 2 to 3 we have absorbed heat (heat is positive).

3-4 adiabatic transformation: $Q_{34} = 0$ no heat exchange with the outside takes place:

V_1= const. → dV = 0 →W_{41} = 0

4-1 isochore transformation: $Q_{41} = \upsilon.Cv\ (T_1 - T_4) < 0 \rightarrow Qrel = Q_{41}$

Because the temperature in state 1 is lower than in state 4

From 4 to 1, heat will be released (negative)

Thus, the efficiency of the Otto engine has the following form: $\eta = 1 - \frac{\nu \cdot C_V (T_4 - T_1)}{\nu \cdot C_V (T_3 - T_2)}$

$$\eta = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

For the adiabatic transformation from 1 to 2 we can write the Poisson equation

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}; \qquad \left(\frac{V_1}{V_2}\right)^{\gamma-1} = \frac{T_2}{T_1}; \quad T_2 = T_1 \cdot \varepsilon^{\gamma-1}$$

For the adiabatic transformation from 3 to 4 we can write the Poisson equation

$$T_3 V_2^{\gamma-1} = T_4 V_1^{\gamma-1}; \qquad \left(\frac{V_1}{V_2}\right)^{\gamma-1} = \varepsilon^{\gamma-1} = \frac{T_3}{T_4}; \quad T_3 = T_4 \cdot \varepsilon^{\gamma-1}$$

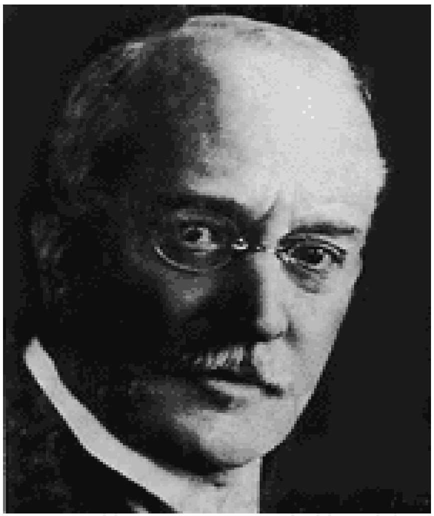
OTTO ENGINE PERFORMANCE ARE: $\Rightarrow \eta = 1 - \frac{T_4 - T_1}{T_4 \varepsilon^{\gamma-1} - T_1 \varepsilon^{\gamma-1}} = 1 - \frac{T_4 - T_1}{\varepsilon^{\gamma-1}(T_4 - T_1)}$

$$\eta = 1 - \frac{1}{\varepsilon^{\gamma-1}}$$

$$\eta = 1 - \varepsilon^{1-\gamma}$$

It can be seen that the yield depends only on the compression ratio ε and the adiabatic coefficient γ.

DIESEL ENGINE


Rudolf Diesel
(1858 - 1913)

HISTORY

Rudolf Diesel (1858 - 1913) was interested in engines. As a youth he was impressed by Lenoir and the steam engine system operating at that time.

During his studies with Prof. Linde, a famous inventor of his time, Diesel learned that heat engines performance can be improved. He referred to the young Frenchman Sadi Carnot (1796 - 1832), who discovered the ideal cycle that bears his name: the Carnot cycle.

Combustion is the basic process in heat engines; thereby, Diesel aimed to continue building such an engine.

In 1890, he had a brilliant idea for a combustion process: an engine that runs on air which is compressed to a pressure of 200 bar.

In this stage, heavy fuel such as oil or diesel is injected through an injector into the air and it heats up to high pressure.

High temperatures lead to immediate self-combustion of the fuel, which leads to disconnection of the spark plug.

The principle was not as simple as it seems. Conversion to practice was problematic, as high pressures and temperatures have not been reached before.

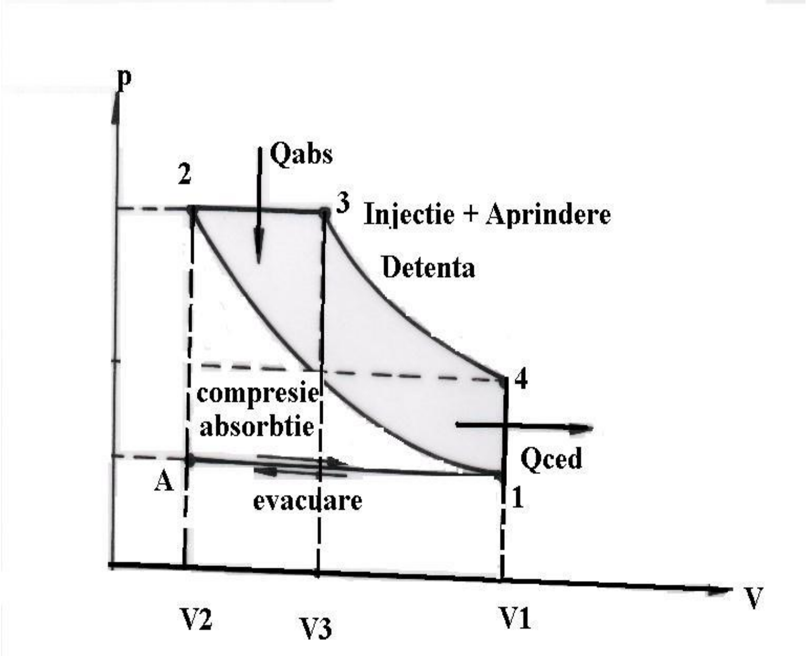
The first experimental engine was built in 1893 at the Augsburg Automobile Factory (MAN) in Germany.

An engine built in 1896 convinced engineers that the 25% efficiency achieved by the diesel engine had never been achieved before. The compression ratio is still low and the maximum working pressure of the engine is 30 bar, even minimal, and additional fuel injection was not possible. It was necessary to use air injection, a complex procedure that required expensive and heavy additional engine components. However, this engine was accepted only with great difficulty due to economic problems and the fuel was very expensive.

Rudolf Diesel has been involved in disputes regarding the patenting of his results and is fighting for his rights. He asked to get a diesel engine, to finally have his own engine. Only in 1908 did he decide to patent his results. He developed a small engine that is used in cars and trucks with a small Swiss company SAURER.

Diesel died in 1913 without believing in the success of his engine.

DIESEL CYCLE PERFORMANCE CALCULATION:



Operating times of the Diesel engine are:

1. **Aspiration A →1**

   (isobar process): p1 = const.

2. **Compression: 1→ 2:**

   (adiabatic transformation): Q = 0

3. **Ignition and retention:**

   2 →3 : p2 = const

   3 →4: Q = 0

   4 →1: V1 = const

In state 3, injection and ignition occur, and in the final state, the exhaust valve opened

4. **Exhaust: 1 →A:** P1=const. (isobaric process)

Operating times of the Diesel engine are

1. Intake

2. Compression

3. Ignition and expansion - power

4. Exhaust

The general formula for calculating the efficiency of a heat engine is:

$$\eta = 1 - \frac{|Q_{rel}|}{Q_{abs}}$$

Qrel - residual heat Qrel < 0

Qabs = absorbed heat Qabs > 0

The compression ratios are given as follows: ρ and ε

$$\rho = \frac{V_3}{V_2} \quad \text{and} \quad \varepsilon = \frac{V_1}{V_2}$$

- **1-2 adiabatic transformation** $Q_{12} = 0$, There is no heat exchange
- **2-3 isobaric transformation** p2=const.

  $Q23 = \upsilon.Cp.(T_3\text{-}T_2) > 0 \rightarrow Q_{abs}=Q_{23}$

because the temperature in state 3 is higher than in state 2

heat from 2 to 3 is absorbed (has a positive value)

- **3-4 adiabatic transformation** $Q_{34} = 0$ there is no heat change
- **4-1 isochoric transformation**: V1=const → dV=0 →W41=0

  $Q_{41} = \upsilon.Cv.(T_1\text{-}T_4) > 0 \rightarrow Qced=Q_{41}$

- The yield of the Diesel cycle is as follows:
- $$\eta = 1 - \frac{\nu \cdot C_V (T_4 - T_1)}{\nu \cdot C_P (T_3 - T_2)}$$
- $$\eta = 1 - \frac{C_V (T_4 - T_1)}{C_P (T_3 - T_2)}$$

$\frac{C_P}{C_V} = \gamma$ - The adiabatic coefficient is the ratio of isobaric molar heat to isochoric molar heat

After substitution we obtain the following yield formula: $\eta = 1 - \frac{T_4 - T_1}{\gamma \cdot (T_3 - T_2)}$

For the 1-2 transformation we use the Poisson equation

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1} \qquad \left(\frac{V_1}{V_2}\right)^{\gamma-1} = \frac{T_2}{T_1} \qquad T_2 = T_1 \cdot \varepsilon^{\gamma-1}$$

For transformation 2-3 we use the equation of an isobaric transformation:

$$\frac{V_2}{T_2} = \frac{V_3}{T_3} \Rightarrow \frac{V_3}{V_2} = \rho = \frac{T_3}{T_2} \Rightarrow T_3 = T_2 \cdot \rho$$

For the 3-4 transformation we use the Poisson equation

$$T_3 V_3^{\gamma-1} = T_4 V_1^{\gamma-1} \qquad T_2 \cdot \rho \cdot V_3^{\gamma-1} = T_4 V_1^{\gamma-1}$$

$$T_1 \cdot \varepsilon^{\gamma-1} \cdot \rho \cdot V_3^{\gamma-1} = T_4 \cdot V_1^{\gamma-1} \qquad T_4 = T_1 \cdot \varepsilon^{\gamma-1} \cdot \rho \cdot \left(\frac{V_3}{V_1}\right)^{\gamma-1}$$

$$\frac{V_3}{V_1} = \frac{\rho}{\varepsilon} \qquad T_4 = T_1 \cdot \rho^{\gamma}$$

Diesel cycle efficiency $\eta = 1 - \frac{T_4 - T_1}{\gamma \cdot (T_3 - T_2)}$

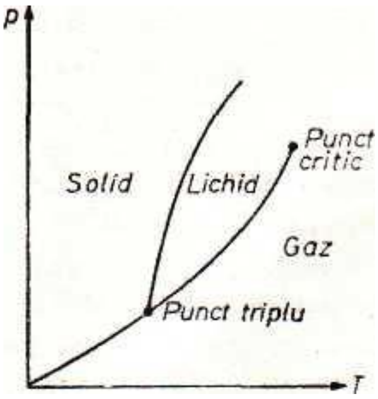
$$\eta = 1 - \frac{T_1 \cdot \rho^{\gamma} - T_1}{\gamma \cdot (T_2 \cdot \rho - T_2)} = 1 - \frac{T_1(\rho^{\gamma} - 1)}{\gamma \cdot T_1 \varepsilon^{\gamma-1}(\rho - 1)}$$

$$\eta = 1 - \frac{\rho^{\gamma} - 1}{\gamma \cdot (\rho - 1)\varepsilon^{\gamma-1}}$$

The efficiency of the diesel engine depends only on the ratio between the compression coefficient and the adiabatic coefficient.

PHYSICS OF LIQUIDS

GENERAL PROPERTIES OF LIQUIDS



INTRODUCTION

Before defining the liquid state and the general properties of liquids, we will describe the solid state and the gaseous state in relation to the liquid state. At sufficiently low pressure, in the (pT) scheme there are two states of aggregation in equilibrium, the solid state and the gaseous state (see Fig. 1.1, which represents the scheme for argon).

Under the action of external stresses, SOLIDS are constantly deformed.

Theoretically, there is an ideal model for solids, *the crystal lattice* in which all nodes are occupied by particles oscillating around the nodes in question. This oscillation causes the thermal motion of a solid.

Gases have fluidity (the property of flowing) and a very low density compared to solids (as in fact compared to liquids), and are highly compressible.

There is also a theoretical model for GA , *the ideal gas* , a set of molecules between which there are no interaction forces, particle-to-particle collisions, and walls are of the central and elastic type. The continuous and perfectly disordered (chaotic) motion of the gas particles characterizes the thermal motion of the gas.

At a higher pressure, above the triple point (see Fig. 1.1), a new state of matter appears, the liquid state between the solid state and the gaseous state.

Since the liquid state is between the solid state and the gaseous state, liquids are continuously deforming, unlike the solid which is constantly deforming, and compared to the gaseous state, they have a much higher density and a much lower compressibility in remote areas.

It can be concluded that liquids differ from gases by density which is higher, compressibility which is lower and the existence of an apparent free surface and they are different from solids because they are permanently deformed and exhibit fluidity (the property of flow).

Thus, **a general definition of the liquid state can be formulated**, obviously not exactly rigorous: **the liquid state is a state of matter, stable, intermediate between the stability region of the solid state and that of the gaseous state for a given density and temperature**.

This is not a rigorous definition, which can be observed immediately, because water is an exception to this rule having a density at 4°C greater than 0°C in the solid state.

But the definition given - with the properties of the liquid state compared to the solid state and the gaseous state - can give a fairly complete picture of the liquid state.

CLASSIFICATION OF LIQUIDS

Liquids can be classified into six groups as follows:

1. Liquids composed of roughly spherical molecules with van der Waals interaction forces (eg Ar, CH_4, etc.);
2. Liquids composed of diatomic molecules such as H_2 , N_2 , etc., similar to those of type 1, but which may have quadrupole moments;
3. Liquid metals, such as Na, Hg, etc., in which Coulomb forces between molecules play an important role;
4. Polar liquids, such as HBr, whose molecules have electric dipole moments;
5. Associated liquids whose molecules have hydrogen bonds, such as, for example, water;
6. Liquids composed of large groups of molecules, where internal motion plays a decisive role.

Some of the liquids contained in categories 1, 2 and 3 form a separate group and are called **SINGLE LIQUIDS**. Only for this type of fluids can a unified theory be constructed with results in good agreement with experimental data.

The liquids of the other groups of liquids form the class of **COMPLEX LIQUIDS** that cannot be satisfactorily described in theory, for different types of liquids and for different temperature ranges various theories have been created that qualitatively describe these liquids.

SIMPLE LIQUIDS are liquids with spherical molecules that have the interaction of van der Waals type forces, unsaturated and unfocused, without dipole moments between them.

This class of liquids includes only pure liquid metals and some diatomic and polyatomic liquids, but much of the information and calculation methods that apply to these liquids can be selectively used in complex liquids as well.

The whole theory of the liquid state is in search of mathematical expressions for various physical quantities, to calculate these expressions based on models and finally to compare the results with experimental data. The theory is based on the assumption that only two particles can interact simultaneously and the interaction of three or more particles is systematically neglected. In addition, it is assumed that the structure of each molecule and the mutual interaction (the interaction between the constituent atoms) can be determined theoretically. In fact, quantum mechanics can solve this in very simple cases, and that is why we prefer to work with empirical interaction potentials.

The thermal motion of a solid is made up of the vibrational motion of particles around lattice nodes, while the thermal motion of a gas is continuous, disordered motion.

The thermal motion of fluid particles is a motion intermediate between the thermal motion of a gas (disordered translational motion) and the thermal motion of a solid (vibrational motion), a combination of translational motion and vibrational motion, not excluding rotational motions.

From the point of view of structure, we imagine the fluid as having centers around which the particles are ordered at a distance of several molecular radii, the centers having a translational motion.

Order is continually breaking down and forming, as if the center of order were to diffuse into the fluid. Quantitatively, this diffusion is characterized by the time t_0, the time when an oscillation center moves a distance equal to the interatomic distance.

Simple liquids have a diffusion coefficient of the order of 10^6 cm^2 /s and

the molecular diameter **a** is of the order of 3-4 Å, thus the time t_0 that characterizes the existence of the local structure is of the order of 10^{-11}s; for solids, t_0 can increase on the order of days.

Liquids behave like solids for times smaller than t_0, the order breaks down to form again immediately around another center. If an external force is applied for very small time intervals - less than t_0 - then liquids exhibit elastic deformations (compressions, dilations and even shear) like solids, deformations that could be demonstrated experimentally.

Solids exhibit long-range structural order, while **order in liquids is order within a few molecular diameters** .

For gases, energetically, thermal energy plays a predominant role compared to interaction forces, which can be neglected (or play only a second-order role).

For solids, interaction forces are predominant, heat plays only a disruptive role.

In the case of liquids, however, interaction forces as well as thermal energy play the same role, being equally widespread.

We can express the characteristic of the thermal movement of liquids : it is a disordered movement, like that of gases, but each molecule interacts simultaneously with a certain number of neighboring molecules.

From the characteristic of the thermal movement of liquids, the fact that interaction forces and thermal energy have the same weighting, the difficulty of choosing a perfect fluid model can be seen.

LIQUID MODELS

The theory of the liquid state was developed in three distinct directions which were essentially determined by the model adopted for the liquid state.

- **THE FIRST DIRECTION** - which actually appeared first **-** is **that in which the liquid state is studied in a similar way to the gaseous state, the van der Waals gas model playing a decisive role in the theory of liquids.** The transition from the liquid state occurs continuously, liquids are just simple condensed gases that maintain the notion of mean free path. There is no order in this model. Liquids are studied in the same way as gases in the so-called kinetic model *(kinetic model).*
- **THE SECOND DIRECTION** in the development of the theory of the liquid state began in the period 1927-1931, with the works of Zernike, Prins, Debye, Lenke, etc., who obtained the first roentgenographic data for liquids and thus the first information about the order existing in liquids. The success of these works was high enough to identify the liquid state from the solid state using the same calculation methods.
- **THE THIRD DIRECTION** in the development of the theory of liquids began with the work of Hildebrand in 1953, who argued against the crystalline conception, creating a proper theory of liquids.

In this conception, the assumptions valid in the two previous conceptions are maintained, according to which the transition from the gaseous state to the liquid state takes place permanently, but there is a local order, order that breaks and forms permanently during the relaxation time t_0. The mathematical theory of the new concept is the theory of correlation functions which was created before 1953 by Kirkwood, Bogooliubov (1942), Born (1947) and which unfortunately presents a lot of mathematical difficulties. In this theory, the radial distribution function g(r) plays a fundamental role, as we will see below.

The three stages of the theory of the liquid state obviously did not develop successively; there were periods when the crystal model was abandoned after a series of failures in resuming kinetic modeling studies and then returning, on other planes, to the crystal model.

No modern fluid theory has developed unitarily over a well-defined period of time.

The division made is dictated rather by didactic considerations in order to form a clearer and more complete idea of the theory of the liquid state.

Numerous crystalline models for the liquid state have appeared, models that today have only a historical role because we have seen that the liquid state cannot be confused with the solid state.

However, the crystal model has been improved by many modifications, so that today, for some temperature ranges, the crystal model is also used with good results, especially for its simplicity and ease of calculation, which make it more accessible than other role models.

The crystal model that has been improved, exists in the following options:

- **the cellular network model *(lattice-cell model)***
- **the Lennard-Jones and Devonshire model**
- **the group of cells model (*cell-cluster model)***
- **the hole model**
- **the tunnel model**

KINETIC MODEL OF LIQUIDS

The fact that around the critical point there is a continuous transition from gaseous to liquid state led to the conclusion - in fact wrong - that there was no difference between liquids and gases.

In the KINETIC MODEL, liquids are considered compressed gases, retaining the notion of mean free path, a notion that is actually quite inappropriate for liquids, given the fact that each liquid molecule is interacting with its nearest neighbors.

The theory was improved in 1935 by Yvon, who determined the probability of a configuration consisting of a small number of molecules. Later, the superposition approximation was introduced by Kirkwood and Boggs, who worked with a hypothetical liquid consisting of spherical molecules.

Born and Green (1947) studied the structure of monatomic liquids from a kinetic model and much later the computer model gave fairly good results for these types of fluids in regions far from the solidification points where crystal theory gives better results.

The kinetic model, with the good results obtained for monatomic liquids, has expanded considerably, especially since this model can describe transport phenomena. Later, independently, the model was improved by Kirkwood and his collaborators between 1946–1954 and Born and Green between 1946–1947. The developed theory satisfactorily describes the phenomena of viscosity and thermal conductivity of liquids.

CRYSTALLINE MODEL

THE CRYSTALLINE MODEL is the model in which the liquid state is designed similarly to the solid, crystalline state.

The first models, where there was a perfect analogy between a solid and a liquid, and which were very numerous, have been replaced because the experimental results did not agree with the theory. For this reason, these models are currently only of historical interest in how the crystalline model was developed.

Later, the entire system was replaced by a cellular network, each cell being a fluid particle. Depending on the shape of the cell and how the particle can move within that cell, a number of crystal models have been constructed. Particles can return to the cell, they can move, but we have not taken into account the correlations that can exist between particles—correlations that play an important role and that were taken into account much later.

As early as 1946, Frenkel had the intuition of the difference between a crystal in which there is long-range order and a liquid in which order appears only at short range.

CELLULAR MODEL

The CELLULAR MODEL, in its original form where each cell is separated by a particle, had to be changed because it is ultimately equivalent to a crystal lattice.

The cellular model was then modified into two versions.

A variant was proposed by Eyring and his collaborators in the period 1936-1941 which took into account the possibility that there are unoccupied cells.

The determination of the average number of unoccupied cells was done by the quasi-chemical approximation by Guggenheim.

The thermodynamics of the cell model was extended to the boundary regions near the critical point, the model being seriously improved by Eyring, Rowlinson and Curtiss.

We will study **the simplest crystalline model, namely the cellular model,** from a quantitative point of view.

It is considered as **a system of cells identical to each other and in each cell is placed a single liquid particle (a molecule) fixed in the center of the cell. The molecule can move around the cell, but its movement is completely independent of the movement of molecules in neighboring cells.**

The simple cell model can be applied around the melting point for accurate values that have been obtained for the number of nearest neighbors.

But the model cannot describe the density fluctuations that occur in liquids due to their thermal motion, and it cannot describe systems of low density except at the melting point.

The model is however very practical, because the mathematical apparatus used is simple, the calculations can be done easily and it can be applied to both monatomic liquids and mixtures, polar or associated liquid solutions.

LENNARD-JONES AND THE DEVONSHIRE MODEL

The system is divided into cells, with the centers of the cells forming a face-centered cubic lattice . The number of molecules is equal to the number of cells, but in this model molecules can move inside the cell but cannot leave the cell, so self-diffusion processes are excluded.

What is important and new in this model is that neighboring molecules can interact with each other.

The version proposed by Lennard-Jones and Devonshire in 1938 - in which the volume of a cell equals the volume per molecule and thus eliminates the void distribution in the system.

The obtained theory is compared with the experimental data, except that the pressure is four times higher than the experimental value.

After 1950, Kirkwood improved the Lennard-Jones theory, considering that there is only one particle in each cell and no correlation between particles, but proposed an additional condition, namely, that the free energy of the system to be minimal.

The energy of the system is considered to consist two components:

- a component equal to [(1/2).N.Eo] is the lattice energy when all molecules are in the equilibrium position
- and the other component is the self-consistent field that replaces the interaction of a particle with all other molecules in the lattice

The theory of LJ and D can be easily applied to quantum liquids by changing the expression of the configuration integral. Liquid hydrogen was studied in this way, for which we obtain for the quantity v/a^3 the value 5/3.

The LJ and D model was then improved to obtain good agreement with the experimental data, not only for areas where the liquid state approaches the solid state.

THE HOLE MODEL

The cellular model, with all its variants, and all its satisfactory results cannot explain the changes that take place in the liquid.

For this reason we had to give up the idea that each cell is occupied by a molecule, so there are empty spaces.

The theoretical hole model was developed by Curtiss and Rowlinson:

The number of molecules N is less than the number of cells.

THE TUNNEL MODEL

The tunnel model is a one-dimensional model of disordered cells.

The whole system is imagined as being divided into subsystems made up of molecules that move in one direction like tunnels.

It is assumed that there is longitudinal movement and transverse movement in tunnels, so it can be treated separately.

If we have K tunnels, there are M molecules in each.

UNIDIMENSIONAL MODEL

As mentioned above, the tunnel model that best describes the liquid state is based on a one-dimensional model of the liquid, the molecules are passed through a tunnel. This is why we study the unidimensional model in more detail, especially since it is very practical to be used when the calculations are approximate.

This model will be employed below.

The one-dimensional fluid model is the simplest way to imagine the structure of a liquid and was proposed by Gürsez. A system of N particles in equilibrium with one degree of freedom (V = L), are arranged on the axis OX of length L in the sequence $0 \leq x_1 < x_2 < ... < x_N \leq L$ so as not to overlap.

The current model - which correctly describes the liquid state that its own model starts from liquids, **based on the thermal motion of the liquid, varies from a proper model, based on the thermal motion of the liquid** , different thermal motions of liquids - gases or solids using the mathematical apparatus of correlation functions.

PHYSICS OF FLUIDS

The fundamental problem is to determine the distribution of pressures and velocities in a fluid.

STATICS OF FLUIDS

In a fluid at rest the pressure is isotropic.

On each surface element of the liquid there is a force perpendicular to the surface and independent of the orientation of the surface element: $d\vec{F} = pd\vec{S}$

HYDROSTATIC PRESSURE

Due to their weight, the fluid layers exert pressure on each other. The pressure variation dp between two flat surfaces (z, z + dz) is given by the weight of the thick fluid layer dz exerted on the surface unit:

$$dp = -\rho g dz\,;\ \frac{\partial p}{\partial z} = -\rho g\,;\left(\frac{\partial p}{\partial x} > 0 si \frac{\partial p}{\partial y} = 0\right) \quad (1)$$

More generally,**the pressure p in a fluid is a function of the point p= p (x, y, z).**

Its variation is due to the weight of fluid layers, namely the presence of the gravitational field (mass forces). The pressure gradient that characterizes the variation of pressure in space and is given by its partial derivatives, is a vector perpendicular to the surfaces of constant pressure (in the direction of increasing pressure), so that "it is perpendicular to the surfaces of the constant gravitational field in the direction of this field.

In the particular case above, these surfaces are horizontal and the vertical field is downward, so the pressure gradient is reduced to vector components only (in the chosen coordinate system).

The general formula:

$$gradp = \frac{\partial p}{\partial r} \cdot \frac{\vec{r}}{r} = \rho \vec{g} = \rho \vec{\Gamma} = \frac{d\vec{F}}{dV} \quad (2)$$

The pressure gradient is equal to the force per unit volume (force of the volume density).

In liquid, the density is practically constant and is obtained by integration: $p_2 - p_1 = -\rho . g .(z_2 - z_1)$

Where : $|\Delta p| = \rho . gh$ (3)

h is the height of the liquid column

PRESSURE UNIT

$$[p]_{SI} = \frac{[F]}{[S]} = L^{-1}MT^{2} = 1\frac{N}{m^2} = 1Pa$$

$$[p]_{CGS} = 1\frac{dyn}{cm^2} = 1 barye$$

Other units currently in use are:

Torr (or mm Hg) is equal to the pressure exerted by a column of 1 mmHg high in a gravitational field (standard)

$$1 Torr = [\rho g h] = 13{,}5951 \cdot 10^3 \frac{kg}{m^3} \cdot 9{,}80665 \frac{m}{s^2} \cdot 10^{-3} m = 133{,}322 \frac{N}{m^2} \approx 133{,}3 \frac{N}{m^2}$$

One physical atmosphere is equal to 760 Torr:

$$1 atm = 760 Torr = 760 \cdot 133{,}322 \frac{N}{m^2} = 101325 \frac{N}{m^2} \approx 1{,}013 \cdot 10^5 \frac{N}{m^2} = 1{,}013 bar$$

technical atmosphere is:

$$1 at = \frac{kgf}{cm^2} = 98066{,}5 \frac{N}{m^2} \cong 9{,}8 \cdot 10^4 \frac{N}{m^2}; 1 at = 735{,}392 Torr \approx 735 Torr;$$

$$1 atm = 1{,}03323 at; 1 atm = 1{,}03323 at \approx 1{,}033 at$$

MILLIMETERS OF WATER COLUMN (mmH_2O)

$$1 mmH_2O \approx 9{,}8 \frac{N}{m^2}; 1 atm \approx 10{,}33 mmH_2O;$$

$$1 Torr \approx 13{,}6 mmH_2O; 1 at \approx 10 mmH_2O$$

PASCAL'S LAW

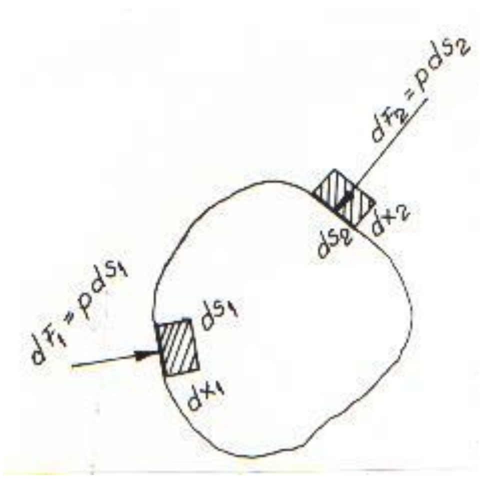


Figure 1. Schematic representation of Pascal's law

Pressure exerted from the outside on the surface of an incompressible fluid is transmitted into the fluid with the same intensity in all directions.

The law can be deduced from theoretical considerations regarding the conservation of energy. The work done by the force dF1 over the distance dX1 must be equal to the work done by the force dF2 over the distance dx2:dF1dx1 = dF2dx2

However, from the incompressibility condition dS1dx1 = dS2dx2 when dividing the two relations member-to-member we obtain:

$$\frac{dF_1}{dS_1} = \frac{dF_2}{dS_2} = p \tag{4}$$

$$\oint_S - p \cdot d\vec{S} = \int_V gradp \cdot dV \tag{5}$$

The right integral of relation (5) is the weight of the fluid inside the closed surface S.

ARCHIMEDES’ LAW

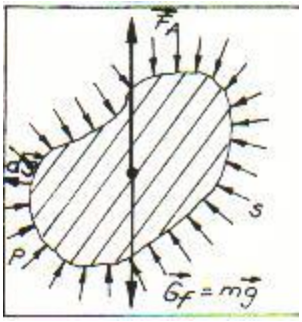


Figure 2. Schematic representation of Archimedes’ law

States:

A body immersed in a fluid is pushed upward with a force equal to the weight of the fluid that was displaced by the body.

Demonstration

A certain volume V of fluid is bounded inside a fluid. We can say that we have bounded it by an infinitely thin, light, perfectly flexible and inextensible film that does not affect the balance of the volume of water thus determined, or we can assume that the volume of fluid has "solidified".

Gravitational force and pressure forces are exerted on this volume of the remaining fluid, forces that are perpendicular to the surface bounding the volume V. Since this volume of fluid is in equilibrium, the resultant of all the pressure forces normally exerted by the remaining fluid on its surface must be equal as normal and opposite to the weight of the delimited fluid having the point of application in the center of gravity of the volume of fluid considered.

Now replacing the volume of the fluid with an identical volume of any body, the resultant of the pressure forces exerted by the fluid on the surface of the body changes nothing, remaining as before, equal in norm and opposite to the weight of the fluid displaced by the body, having the point of application at the center of gravity of the volume of fluid displaced (the center of pressure).

Proof of Archimedes' law based on the hydrostatic formula:

The resultant of the pressure forces is:

$$\oint_S (-p)d\vec{S} = \int_V (= gradp)dV = -\int_V \rho\vec{g}dV = -\int_V \vec{g}dm = -\vec{G}_f \quad (6)$$

The first integral is the sum of all the pressure forces exerted on a closed surface S inside the fluid and bounded by the volume V.

From the mathematical expression we obtain:

The resultant of the pressure forces exerted on a closed surface inside a fluid is equal in norm and opposite in direction to the weight of the liquid contained by this surface.

Moment resulting from pressure forces:

$$\oint_S \vec{r}\times d\vec{F} = \oint_S \vec{r}\times(-p)d\vec{S} = -\oint_S p\vec{r}\times d\vec{S} = \int_V rot(p\vec{r})dV = \int_V gradp\times\vec{r}dV = -\int_V \vec{r}\times\vec{g}dm = -\int_V \vec{r}\times d\vec{G} \quad (7)$$

The following calculation was performed:

$$\oint_S \vec{a}\times d\vec{S} = -\int_V rot\vec{a}dV$$

and

$$rot\left(f\vec{a}\right) = gradf\times\vec{a} + frot\vec{a}$$

The moment resulting from the pressure forces exerted on a closed surface of a fluid is equal as a standard and opposite to the moment resulting from the gravitational forces of the volume of liquid contained in this domain.

The apparent weight of a body immersed in a fluid is given by:

$$G_a = mg - \rho_f V.g = mg\left(1-\frac{\rho_f}{\rho_s}\right) \quad (9)$$

$$G_a = mg - \rho_f V.g = mg\left(1-\frac{\rho_f}{\rho_s}\right) \quad (10)$$

- **if ρf < ρs the body sinks**
- **if ρf > ρs the body rises to the surface (floats)**

Where:

- ρf is the density of the fluid and
- ρs is the density of the solid

FLUID FLOW

The amount of liquid dm that passes in time dt through a surface element dS is: $dm = \rho dS_{\perp} v \cdot dt = \rho d\vec{S} \cdot \vec{v} \cdot dt = \vec{\mu} \cdot d\vec{S} \cdot dt$ (11)

Where:

$\vec{\mu} = \rho \cdot \vec{v}$ is the flow density of the fluid, equal to the mass of the fluid passing per unit time per unit area placed perpendicular to the direction of the current:

$$\mu = \frac{dm}{dS_{\perp} dt} = \rho v; \vec{\mu} = \rho \cdot \vec{v}$$

THE CONTINUITY EQUATION

The fluid is characterized by the velocity distribution (vector field)

$\vec{v} = \vec{v}(\vec{r}, t)$

and pressures (scalar field): $p = p(\vec{r}, t)$

If the velocity and pressure do not depend on time, the flow rate is stationary and is considered a constant basis.

STABILITY CONDITIONS

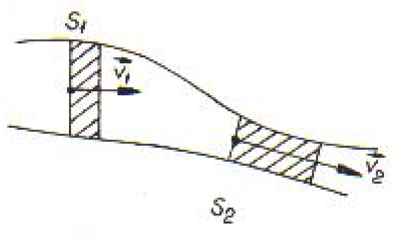


Figure 3. S1 and S2 two sections where the liquid flows at different velocities v1 and v2

In the case of a stable (permanent) regime, the density of the fluid does not depend on time $\frac{\partial \rho}{\partial t} = 0$

and $div \rho \vec{v} = 0$ (21)

or $\int_V div\rho\vec{v}dV = \oint_S \rho\vec{v}d\vec{S} = 0$ (22)

We apply the last equation for a current tube between two sections S1 and S2. On the side surface we have: $\vec{v}\cdot d\vec{S} = 0$

Here is why: $\oint \rho\vec{v}\cdot d\vec{S} = \int_{S_2} \rho\vec{v}d\vec{S} - \int_{S_1} \rho\vec{v}\cdot d\vec{S} = 0$ (23)

where the two integrals of the right element are taken in the direction of flow.

As a result: $Q_m = \int_{S_1} \rho\vec{v}d\vec{S} = \int_{S_2} \rho\vec{v}d\vec{S} = cons\tan t$ (24)

In a steady state, the constant mass flow rate Qm is the same in each section of a stream tube.

For a thin tube, so that the fluid density and velocity at the tube section are nearly constant, we obtain:

$$Q_m = \rho_1 v_1 S_1 = \rho_2 v_2 S_2 = \rho v S = cons\tan t \tag{25}$$

INCOMPRESSIBLE FLUID

Thus, in the case of incompressible fluid flow, so that the volume flow rate and mass flow rate are constant along a flow tube.

Taking the average velocities on the tube section, equation (29) becomes: Qv= <v >S=const. (30.1)

and

Qm= <v >S=const. (30.2)

Where the tube narrows, the velocity of the fluid increases.

So where the streamlines thicken, the fluid velocity increases.

BERNOULLI'S LAW

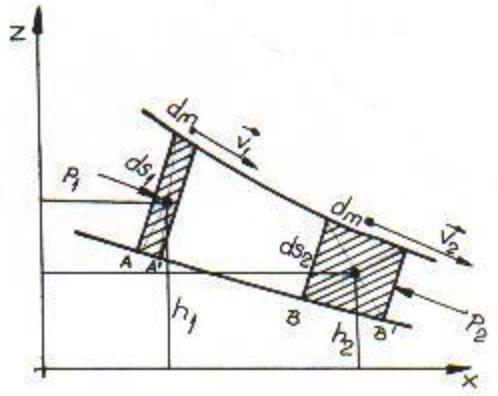


Figure 4. Schematic representation for Bernoulli's law

An incompressible fluid without viscosity is considered an <u>ideal fluid.</u>

Ideal fluids can be considered incompressible with fairly good ion accuracy.

Although gases are easily compressible, their compressibility occurs only at speeds close to the speed of sound.

Experience shows that a large number of liquids and even gases, if their velocities are much lower than the speed of sound, the velocity gradients are small, correspond satisfactorily to the ideal fluid.

Nevertheless, in the following paragraph, the perfect fluid flow will be studied.

BERNOULLI'S LAW - Demonstration

Let us consider the ideal fluid and an infinitely thin current tube, bounded at the ends by two sections dS1, dS2 and apply to the amount of liquid thus bounded the theorem of variation of mechanical energy.

During dt the system moves along the tube from position A'B AB".

Everything happens as if the mass "disappears" from the AA portion.

$$dm = \rho.dS1.v1.dt = \rho.dV \qquad (31)$$

with kinetic energy $\frac{dm \cdot v_1^2}{2}$

and the potential energy dm.g.h1

In the portion BB, an equal mass appeared (due to the incompressibility of the ideal fluid): dm = ρ.dS2.v2.dt= ρ.dV

with kinetic energy $\frac{dm \cdot v_2^2}{2}$

and the potential energy dm.g.h2.

The change in mechanical (kinetic and potential) energy of the system is therefore: $dE = \frac{1}{2}dm\left(v_2{}^2 - v_1{}^2\right) + dm \cdot g\left(h_2 - h_1\right)$(32)

and must be equal to the work of the pressure forces exerted on the system in question:
dW = F1.dx1-F2.dx2 = p1.dS1.v1.dt - p2.dS2.v2.dt == P1.dV- p2.dV (33)

and $dV = \frac{dm}{\rho}$

Lateral pressure forces do not work and we have no tangential friction force, the fluid is assumed to be perfect (no viscosity) dE = dW

SO: $p_1 + \frac{1}{2}\rho v_1{}^2 + \rho g h_1 = p_2 + \frac{1}{2}\rho v_2{}^2 + \rho g h_2$ **(34)**

Or $p + \frac{1}{2}\rho v^2 + \rho g h = const.$ **(35)**

Bernoulli's law

The constancy generally differs from one streamline to another (it is the same for flow without eddies).

- **p is the static pressure**
- **$p_d = (1/2)\cdot\rho\cdot v^2$ - dynamic pressure** (due to the kinetic energy of the fluid is equal to the kinetic energy of the unit volume)
- **$p_p = \rho\cdot g\cdot h$- pressure position** (or potential pressure due to potential energy equal to the potential energy of unit volume)
- **Bernoulli's law**

The total pressure in a fluid is constant along a streamline.

Static pressure is exerted on a surface element arranged parallel to the flow lines, for example on the walls of the tube (sometimes called wall pressure) or exerted on an arbitrarily oriented surface element but displaced relative to the fluid.

Static pressure is measured with a pressure probe.

Dynamic pressure is measured with a Prandtl tube.

The total pressure is exerted on a placed surface element, perpendicular to the flow lines and is measured with the pitot tube having the opening placed perpendicular to the flow lines.

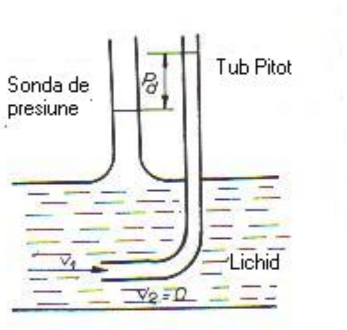
For horizontal tubes, Bernoulli's principle is:

$$p_1 + \frac{1}{2}\rho v_1{}^2 = p_2 + \frac{1}{2}\rho v_2{}^2 = p + \frac{1}{2}\rho v^2 = const.$$

HYDRODYNAMIC PARADOX

When particles enter the narrow portion of a flow tube, their velocity increases (when the flow rate is constant), meaning that they move faster as a result of the fluid pressure in the wide part of the flow. The tube must be larger than the narrow part.

In the narrow portion of the tube the velocity increases (according to the continuity equation) and the dynamic pressure also increases, so the static pressure must decrease, i.e. the pressure on the walls so that their sum remains constant, according to Bernoulli's Equation (Hydrodynamic PARADOX)

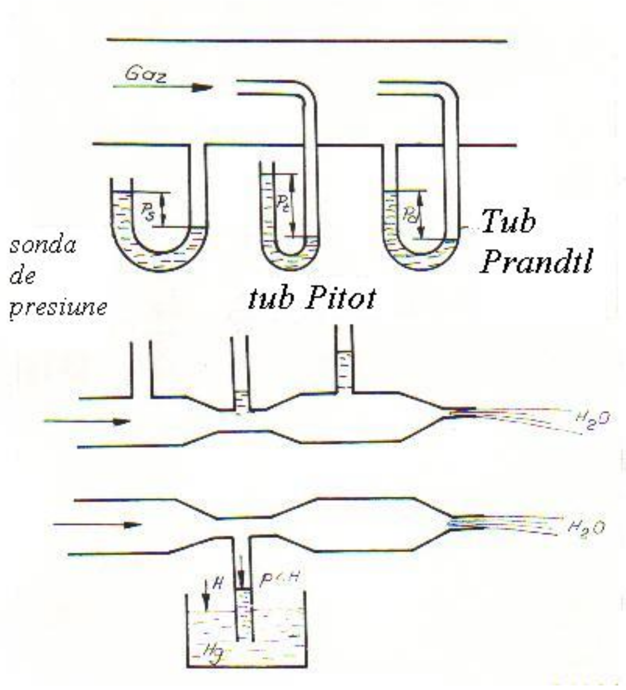


Sprayer, water pump, Bunsen lamps

The pressure in the throat can drop even below atmospheric pressure, so that the phenomenon of aspiration occurs.

The name of this practical application includes: Sprayer, Water Pump, Bunsen Lamps.

This application is based on the phenomenon of aspiration.



VISCOSITY

At <u>not too high velocities, fluid flow is linear</u> (in parallel layers), that is, the flow lines are well defined and do not intersect, each fluid particle slides always remains in the same stream tube.

<u>At higher speeds, the movement of the fluid is turbulent, irregular, the portions of the fluid mix with each other</u>. There is also the ideal vortex fluid flow.

<u>If layers of fluid slide against each other, internal friction or viscous forces occur between them.</u> The lower velocity layer brakes the higher velocity layer and vice versa, the higher velocity layer brakes the lower flow velocity layer.

The appearance of these forces, located in the sliding planes, is explained by the momentum variation of the layers due to the passage of molecules from one layer to another. We will assume that the direction of fluid flow is the same everywhere, and the flow velocity varies its norm or modulates only in the direction perpendicular (transverse) to the direction of flow.

The example shows that **the internal friction force appearing in the sliding plane per unit area is proportional to the velocity gradient,** i.e. **the variation of velocity with distance (NEWTON'S LAW):**

$$\tau = \frac{dF}{dS} = \eta \frac{dv}{dz} \qquad (38)$$

thus,

$$dF = \eta \frac{dv}{dz} dS \qquad (39)$$

Where η is the coefficient of dynamic viscosity and it depends on the nature of the fluid (and the temperature).

The unit of measure of the viscosity coefficient is the following:

$$[\eta]_{S.I.} = \frac{N \cdot m}{m^2 \cdot \frac{m}{s}} = \frac{N.s}{m^2} = Pa.s = \frac{Kg \cdot m \cdot s}{s^2 \cdot m^2} = \frac{Kg}{m \cdot s}$$

$$[\eta]_{S.I.} = \frac{N \cdot s}{m^2}$$

The CGS unit is <u>the poise</u> (P) (after Poiseuille name):

$$1P = 1\frac{g}{cm \cdot s} = 0{,}1\frac{Kg}{m \cdot s}$$

Then the SI unit **is DECAPOISE (daP)**

for liquids: $\eta \sim 10^{-3}$ daP

for gases: η ~10^{-5} daP

KINEMATIC VISCOSITY

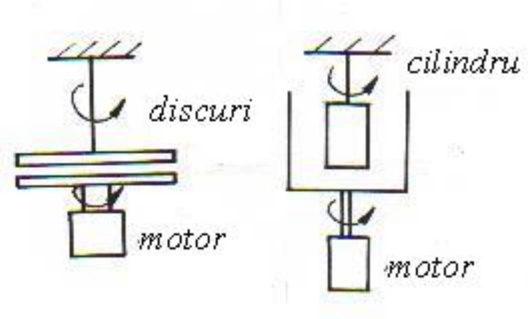
<u>KINEMATIC VISCOSITY</u> is the ratio between the viscosity and the density ρ of the fluid:

υ= η/ρ

And its unit of measurement is: $[\nu]_{S.I} = 1\frac{Kg}{m \cdot s} \cdot \frac{m^3}{Kg} = 1\frac{m^2}{s}$

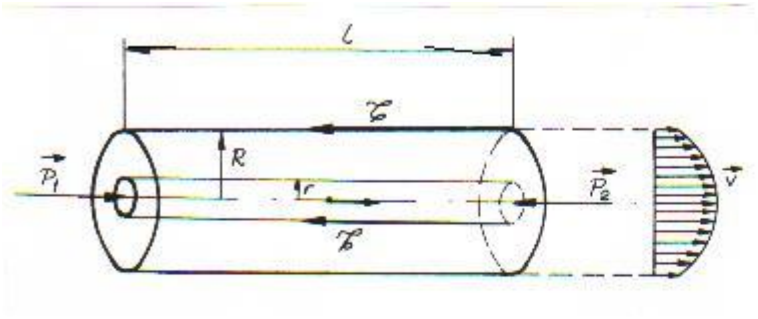
In the CGS system the unit is called STOKES (St) $1St = 1\frac{cm^2}{s} = 10^{-4}\frac{m^2}{s}$

- For liquids υ ≅10^{-6} m^2/s
- For gases υ ≅10^{-5} m^2/s (is higher than liquids)



The existence of internal friction (viscosity) is demonstrated experimentally using a thread that suspends a disk or cylinder under which another disk or cylinder rotates. The layer of fluid in the immediate vicinity of the rotating body adheres to this body and is carried by it. The other layers are driven at lower and lower speeds until the last layer adheres to the other disc or cylinder on which a frictional force is thus exerted which will cause it to rotate. (see the figure).

POISEUILLE FORMULA



Let us study the steady linear flow of a viscous fluid through a tube.

Linear flow occurs at not too high velocities or diameters.

Delimit a current tube of radius r (see figure). The fluid of this tube is subjected to the pressure forces exerted at the ends of the tube having the resultant ($p_1\pi r^2 - p_2\pi r^2$) and the internal frictional force exerted on the lateral surface of the tube by the rest of fluid due to viscosity.

The flow being stationary (constant speed), the forces are balanced:

$$p_1.\pi.r^2 - p_2.\pi.r^2 = 2.\pi.r.l.\tau$$

The internal frictional force on the lateral surface exerted by the fluid due to viscosity is τ.2.π.r.l

The flow being stationary (constant speed), the forces are balanced:

$$(p_1 - p_2).\pi.r2 = 2.\pi.r.l.\tau$$

Or

$$(p_1 - p_2)r = -2l\eta \cdot \frac{dv}{dz} \qquad (40)$$

τ - is the internal friction force

The minus sign appears due to the gradient of the minus sign in the velocity.

The velocity is maximum on the axis of the tube and decreases on the walls of the tube being zero in the layer adjacent to the walls $\frac{dv}{dz} \langle\ 0$.

By integration $dv = -\frac{p_1 - p_2}{2l\eta} r dz$,

we obtain: $v = -\frac{p_1 - p_2}{4l\eta} r^2 + C$

The constant C is determined by the condition that at the wall for r = R, its velocity is zero.

$$v(r) = \frac{p_1 - p_2}{4l\eta}\left(R^2 - r^2\right) = v_m\left(1 - \frac{r^2}{R^2}\right) \qquad (43)$$

Or $\quad v_m = \frac{(p_1 - p_2)R^2}{4l\eta}$

thus $\quad \frac{v}{v_m} = 1 - \frac{r^2}{R^2} \qquad (44)$

The velocity distribution is parabolic.

To calculate volume flow:

$$Q_v = \int vdS = \int_0^r v \cdot 2\pi r \cdot dr = \int_0^r \frac{2\pi(p_1 - p_2)}{4l\eta}(R^2 - r^2)rdr = \frac{2\pi(p_1 - p_2)}{4l\eta} \cdot$$

$$\cdot \int_0^r (R^2 - r^2)rdr = \frac{\pi(p_1 - p_2)}{8l\eta}R^4 = Sv \qquad (46)$$

$$where \qquad v = \frac{p_1 - p_2}{8l\eta}R^2$$

$$Q_v = \frac{\pi(p_1 - p_2)}{8l\eta}R^4 = Sv$$

$$ou \quad v = \frac{p_1 - p_2}{8l\eta}R^2 \qquad (47)$$

This is Poiseuille's formula (1841).

The flow rate Q is proportional to the pressure loss (p_1-p_2) per unit length at the tube and is proportional to the fourth power of the tube radius.

This formula can be used to determine the viscosity of fluids (eg in the OSTWALD viscometer).

Poiseuille's law explains certain aspects of the physiology of blood circulation. *The human capillary network totals 10^5 km.*

Depending on the needs of the body, the blood flow can be easily adjusted by the contraction or dilation of the blood vessels.

BOUNDARY LAYER. STOKES LAW

When a body moves through a fluid, a very thin layer of fluid, dragged by the body, adheres to its surface. In the linear regime, that is, at not too high speeds, near the body there is a relatively thin layer, called the **boundary layer**, in which the speed drops to zero and frictional forces are exerted due to viscosity.

The thickness of the boundary layer is evaluated as follows: the length and width of the boundary layer are denoted by h and b. Then the internal friction force, according to **Newton's law is:** $\mathbf{F \cong \eta.(v/d).\,hb}$ (48)

On the other hand, the internal friction force can be determined from the change in fluid momentum (from the zero-velocity layer to the v-velocity layer) per unit time: $\mathbf{F \cong Q_m.v = \rho.dbvv = \rho.dbv^2}$ (49)

From these two expressions result: $d \cong \sqrt{\frac{h\eta}{\rho v}}$ (50)

If the ratio (hb)/d=l is a characteristic length of the body, then the frictional force becomes:

$\mathbf{F = const.\ \eta.lv}$ **- Stokes' Law** (51)

STOKES LAW: the friction force F experienced by a body (in the flow regime) is proportional to the viscosity of the fluid η, to the linear dimension characteristic of the body and to its velocity v.

In the case of the sphere, we get the Stokes formula

$\mathbf{F = 6.\ \pi.\ \eta.rv}$ (52)

where r is the radius of the sphere.

APPLICATIONS: HEMODYNAMICS

The physics of blood circulation is an application of the laws of hydrostatics and hydrodynamics.
Hemodynamics is today considered a chapter of rheology, the science of viscous fluid flow.
The difficulties of implementing the laws of hydrodynamics in hemodynamics are due to the extensibility of the vessels, their variable caliber depending on the physiological conditions (this caliber is influenced by arterial pressure, carbon dioxide content, innervation and hormones) as well as the non-constant character of the vascular flow in most parts of the system.

The density of human blood is approximately 1.655 g/cm^3.
The pressure of 1 mm Hg = 1331 dyn/cm^2 is equivalent to 1.20 cm^3 of blood.
In the heart, blood pressure is pulsatile, averaging about 100 mm Hg, which corresponds to 129 cm^3 of blood.
In the horizontal position of the human body, the average arterial pressures in the brain and legs are approximately equal.
In an upright position (orthostatism) blood pressure of 80 mm Hg in the brain is lower and is higher in the legs (200 mm Hg).

APPLICATIONS: HYDROSTATICS OF BLOOD

"HYDROSTATIC FACTOR"

This factor explains the aviation accidents observed during accelerations to loops, as well as the difficulties of pilot training on a multirole combat aircraft (light fighter).

Under these conditions, the blood is subjected to the action of inertial forces corresponding to a multiple of g.

For a centripetal acceleration equal to 3 g, the hydrostatic factor in the cerebral arteries is 111 mm Hg.

Lowering this value to the average value of 100 mm Hg at the level of the heart results in a negative pressure inside the arteries of the brain, inside the atmospheric pressure; the arteries are flattened, closed, blood does not circulate in the brain.

On the other hand, if the force of inertia is oriented in the opposite direction, congestion of the brain and retinal vessels occurs, with visual disturbances.

In the state of weightlessness ($g = 0$), the pressures in the circulatory system are independent of position.

In the veins, the same hydrostatic factor acts, except that the related peripheral veins have valves that fragment the blood column. If a vein in the leg is cannulated and connected to a long vertical tube containing saline, its level rises close to the level of the heart (with the subject standing). When the muscles of the legs contract, the veins are "massaged" and the blood is pushed up, the valves preventing the blood from returning to the lower areas (muscle pump). Standing or sitting immobility favors, by increasing venous pressure, the passage of fluid from the bloodstream into the legs (dependent edema).

The movement of blood through blood vessels must overcome certain resistances.

There is an adhesive force between the liquid and the solids it wets, a force which prevents the movement of the fluid layer in the vicinity of the wall;

Then there is the viscosity that opposes the sliding of one layer over a neighboring layer of blood.

The layer adjacent to the wall has zero velocity, while the axial layer has the maximum velocity.

When the velocity is moderate and the tube diameter not very large, the flow is laminar (no eddies).

If the flow regime is invariant with time, the flow is called steady.

In a cylindrical tube, the layers of fluid in laminar and steady flow are coaxial cylinders.

Hagen showed that the velocity v_r at a point located at a distance r from the axis (where the velocity is maximum, v_m) is given by: $v_r = v_m \left(1 - \frac{r^2}{R^2}\right)$

where R is the tube radius.

Consequently, the distribution of rays follows a parabola.

The value of v_m depends on the pressure gradient along the tube, the radius R and the viscosity: $v_m = \frac{\Delta p}{\Delta x} . \frac{R^2}{4\eta}$

APPLICATIONS: BLOOD FLOW

The viscosity of water at body temperature is 0.69 centipoise and **blood viscosity is three or four times higher for a normal number of red blood cells.**

Blood is not a Newtonian fluid. As the percentage of red blood cells in the blood volume increases, the viscosity increases rapidly, following an almost exponential curve. When the amount is greater than 70% of the hematocrit, the blood cannot be considered fluid. In anemia, low viscosity can cause circulatory disorders and heart activity.

When the temperature drops, the viscosity of the blood increases greatly which is considered to be an important factor in reducing the circulation to the extremities exposed to the cold (this is the case of frostbite).

TR Fahraeus and Lindqvist discovered that, unlike water, the value of blood drops significantly if the diameter of the tube is less than 1 mm (sigma effect). If d is the diameter of the erythrocyte and the effective viscosity in a tube of infinite radius, the effective viscosity in a tube of radius R is given by:

$$\eta_R = \eta_\infty / (1 + \frac{d}{R})^2 .$$

Laminar and turbulent flow applications

Poiseuille's law shows a linear relationship between matrix pressure and flow, only for a certain range of velocities.

The critical flow velocity changes the slope of the curve and the curve flattens.

The critical point is the point where the laminar flow turns into a turbulent flow, vortex.

In turbulent flow, the resistance is not only given by the viscosity of the fluid, but also by the loss of energy in the form of kinetic energy from the vortex.

The critical speed is given by: $v_c = (K.\ \eta\rho)/R$

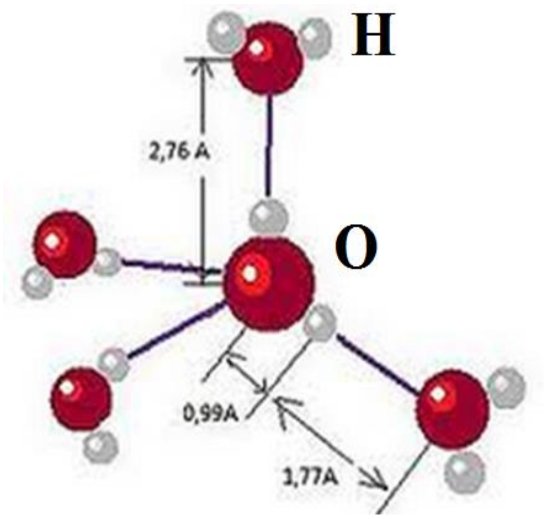
where K ≅1000 is called the Reynolds number (v_c is given in $cm.s^{-1}$, η in poise, ρ in $g.cm^{-3}$ and R in cm).

For the aorta (R = 1 cm), (blood viscosity) $\eta = 0.001\ g.cm^{-3}$, $v_c = 40\ cm.s^{-1}$.

The average speed of the blood in the aorta can be calculated from the flow, that is, by dividing 83 $cm^3.s^{-1}$ by the cross-sectional area 4 cm^2;

$Vm = 20\ cm.s^{-1}$

WATER MOLECULE



OH=0.99Å

OO = 2.76 Å

HH = 1.77 Å

There are H and O isotopes in nature as follows:

$^{1}_{1}H\ ,^{2}_{1}H,\ ^{3}_{1}H$

$^{16}_{8}O,\ ^{17}_{8}O,\ ^{18}_{8}O$

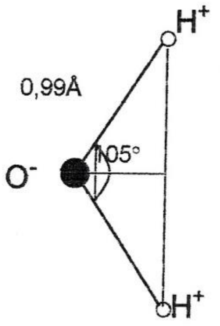
There can be 18 species of water molecules.

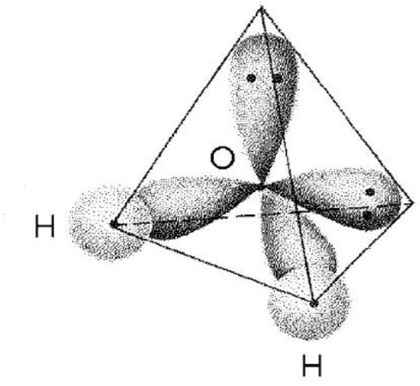
The electronic structure of the water molecule.

$^{1}_{1}H \qquad Z = 1 \qquad 1s^{1}$

$^{16}_{8}O \qquad Z = 8 \qquad 1s^{2} \quad 2s^{2} \quad 2px^{2}\ 2py^{1}\ 2pz^{1}$

WATER - STRUCTURE AND PHYSICAL PROPERTIES





- The water molecule has coplanar atoms.
- The angle between the two O-H bonds = 105°.
- O-H bond length = 0.99 Å.
- Since the O atom is more electronegative than H, the pair of electrons in the O-H covalent bond is more attracted to the O atom.
- There is a dipole moment of 1.5 D (Debye) in the O-H bond which gives a vector sum for the H_2O molecule of a dipole moment of 1.84 D.
- The angle between the two O-H bonds is 105° to 109o – which is the angle between the sp^3 hybrid orbitals .
- Of the four sp3 valence orbitals of the O atom, two are involved in OH bonds and two have a pair of non-participating electrons.
- Hydrogen bonds are formed between the OH bonds and the non-participating electrons of the O atom.
- The distance between the two O atoms in the water molecule located at the ends of a hydrogen bridge is 2.76 Å.
- The hydrogen bond energy is 5 kcal/mol.
- The energy required to dissolve the OH covalent bond is 110 kcal/mol.
- With two OH bonds and two nonparticipating electron pairs, a H_2O molecule participates in four hydrogen bonds and is a proton donor for two.
- The two OH bonds and two non-participating electron pairs face up in the center of a tetrahedron.
- H-bonds are the basis of the formation of supramolecular structures for ice and liquid water.

Water can exist in the following states of aggregation:

- solid (t < 0°C)

- liquid (t = 0-100 ^{o}C and p = 1 atm)
- gas (t > 100°C)

The structure in the gaseous state is quite hollow, with a calculated density of about 0.9 g/cm^3.

The tetrahedral shape changes as the ice melts, the latent heat of fusion is required to change the configuration.

The destruction of the crystal configuration causes certain areas of the crystal to be occupied by other water molecules, which explains the increase in the density of water at 4°C when the maximum density is 1 g/cm^3. As the temperature rises above 4°C, sufficient thermal motion occurs which lowers the density of water molecules above this temperature.

For a water molecule to freeze, it would have to give 1.44 kcal to the middle (the hydrogen bond energy of ice is 10 kcal/mol).

From this energy balance we can deduce that about 15% of the hydrogen bonds are broken when the ice melts.

The upshot of all this is that water still contains 85% of its hydrogen bonds after the ice melts, so the spatial configuration changes.

Physical properties of water

Density	water	1000 kg/m^3
	ice	920 kg/m^3
Specific latent heat	fusion	340,000 J/kg
	vaporization	2,250,000 J/kg
Specific heat	water	4185 J/(kg.K)
Surface tension	water	72.8. 10^{-3} N/m
Electrical resistance	ρ at 25 ^{o}C	182.103. Ωm
Electrical conductivity	σ at 25 ^{o}C	5.5.10-6 Ω^{-1} .m^{-1}
Electrical permittivity	εr	80

Effects of solvates on the molecular structure of water

After dissolving the substances in water, the molecular structure of the water changes, due to the interactions of different types that take place between the water molecules and the molecules or ions of the solvates.

When dissolved in water, a strong electrolyte dissociates into positive and negative ions.

Permanent ion-dipole interactions occur between these ions and water molecules, which determine the orientation of the water dipoles around the ions (the oppositely charged end located near the ion).

The phenomenon is called hydration of the ion.

The coordination or **coordination number** or **coordination index** of a water atom is the number of nearest neighbor atoms in the three directions of space.

Properties of hydration water:

- increased density
- increasing the melting point and the boiling temperature t

ion	**coordination number**
Na^+	8
K^+	4
$Ca2^+$	10
Cl^-	2

THE BIOLOGICAL ROLE OF WATER

1. **Water is the main constituent of living matter.**
2. Water is the universal solvent of intra- and extracellular living matter.
3. Water regulates the osmotic pressure of the three water sectors through the following mechanisms:
    - diffuses through the biological membranes that separate the fluid spaces
    - is eliminated or retained in the body as needed
    - the volume of liquid can be obtained by ingesting water
4. Water is the environment in which multiple chemical and biochemical reactions of the body take place (hydrolysis, oxidation, through hydrogen ions participate in enzymatic reactions)
5. Water helps maintain a constant body temperature (thermoregulation)
6. Water is a good solvent to form a series of molecular solutions, or colloidal substances, which circulate from the internal environment of the body to the cell and vice versa (allows the transport of waste from cellular metabolism to the organs of excretion)
7. Water helps eliminate waste from the body through the kidneys
8. Water plays an important role in protecting the fetus

CLASSIFICATION OF BODY WATER

Depending on where it is in relation to other cells:

- intracellular
- extracellular
    - interstitial (extravascular)
    - circulating (intravascular)

Depending on its tissue distribution:

- tissue water
- cavity water (aqueous and vitreous humor, cerebrospinal fluid)

Depending on the chemical state:

- free water
- bound water
- structured water

FREE WATER – is the set of extracellular molecules that circulate through the extracellular spaces and around the macromolecular complexes inside the cells.

FREE WATER :

- is the solvent for substances in aqueous medium
- produces osmotic pressure
- transport nutrients from the external environment to the cell
- transports the residues of catabolic processes from the cell to the outside

BOUND WATER - is the fraction bound to macromolecules: proteins, nucleic acids, macromolecular complexes through polar, hydrophilic groups.

The arrangement around protein formations is ordered according to the electrical forces present on the surface of these molecules.

The appearance of the water arrangement is more disorganized, more chaotic as the distance between the central protein molecule and its surrounding layers increases.

The importance of bound water is remarkable from a metabolic point of view, indirectly revealing the level of metabolic activity of the body. The greater the amount of bound water, the more intense the exchanges with the environment.

From the RMN analysis, it was concluded that the volume of bound water decreases in malignant tumors compared to normal tissues.

Bound water properties:

It has a very low freezing temperature (below 20°C).

It is very resistant to drying.

Does not show traces of solvent.

It cannot cross the membrane during osmotic exchanges between the cell and the interstitial medium.

It is non-transferable by osmosis.

STRUCTURED WATER is intermediate in nature between free and bound water.

It enters the composition of food (proteins, carbohydrates and lipids) when they are stored in the form of macromolecules.

Through the degradation of the stored substances, the structured water is released and joins the free water in the environment.

According to our origin we distinguish:

- exogenous water (brought from outside the body, water consumption per day for humans is 2 L)
- endogenous water (produced by metabolic processes and it is 0.3L/day)

Body water distribution (%)

- **70% of the body is water**
- **there are variations by age and gender**

	Total water	**Intracellular water**	**Extracellular water**		
			plasma	interstitial water	total water
Children	75	45	4	26	30
Men (adults)	60	40	3	15	20
Women (adults)	50	35	4	11	15

Z. Simon, Fl. Rotemberg, GI Mihalas, Biophysics, Lito IMT, 1989, p.39

Age	**Total water**	**Intracellular water**	**Interstitial water**	**Plasma**
Newborns	75	35	35	5
Less than 1 year old	70	35	30	5
1-10 years	60-65	35-40	20-25	5
10-50 years	55-60	40-45	15	5
Over 50 years	50-55	35-40	10	5

Rodica Caprita, Biophysics, Ed. Mirton, Timisoara, 2000, p.87

Body water distribution (%)	
Tissues / organs	water (%)
hair	4
dentine	10
skeleton	30
nervous tissue	70
lungs	81
brain	85
blood plasma	93
embryonic tissue	97

According to (A. Neagu, M. Neagu, Biophysics Course for the Faculty of Dental Medicine, Ed. Eurobit, 2007)

Body water distribution (%)	
Tissues / organs	water (%)
adipose tissue	10
Bone tissue	22
liver	68.3
skin	72
intestine	74.5
brain	74.8
muscle	75.6
spleen	75.8
lungs	79
heart	79.2
kidney	82.7
blood	83

According to (Rodica Caprita, Biofizica, Ed. Mirton, Timisoara, 2000, p.87)

THE ENTRANCE AND REMOVAL OF WATER FROM THE BODY

When there is no quantitative difference between the consumption of water and its elimination, the water balance is equilibrated.

Qintake = Qremoved –

Where Qintake, Qremoved are the flow rates corresponding to water supply and removal, respectively.

Qintake > Qremoved – water imbalance is positive – edema occurs.

Qintake < Qremoved - water imbalance is negative - acute dehydration occurs.

The water intake in 24 hours is:

- 2500 mL - in adults
- 2700 mL - in children

These quantities come from:

- 1200 mL from ingested water
- 300 mL from oxidation of organic substances and
- 1000 mL from food

Excessive water intake leads to water intoxication and is explained by the reduced intracellular concentration of electrolytes.

Elimination occurs largely through:

- Urine: 1200 mL
- Skin: 800 mL
- Breath: 400 mL

The extent to which a substance is absorbed into the blood and excreted in the urine is expressed by what is called: **Renal clearance** - defined as follows:

$$C_{H_2O} = Qu / cp$$

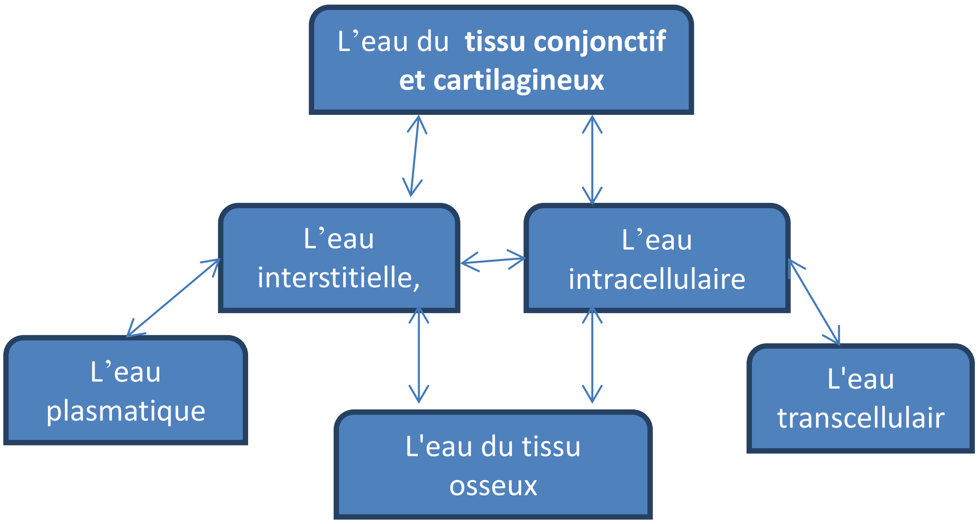
Where: Qu - the amount of matter to urinate per unit of time

CP - the concentration of matter in the plasma

Water balance disorders generate functional changes especially in children, as they have a more intense metabolism that requires a volume of water in 24 hours approximately six times higher than in adults.

Acute dehydration occurs more frequently the younger the child's age. Premature infants are more susceptible due to massive skin loss and immature renal concentrating mechanisms.

Circulation of water between different body compartments



(Z. Simon, Fl. Rotemberg, GI Mihalas, Biofizica, Lito IMT, 1989, p.40)

LIQUIDS - PHYSICAL AND CHEMICAL PROPERTIES

INTRODUCTION

Today, doctors and researchers believe that the acidity of the liquids and foods we consume contributes to diseases such as obesity, cancer and diabetes, thus to control the level of acidity in the body, it is necessary, first of all, to pay attention to food consume, and secondly to drink water, natural or sparkling, with a neutral pH.

The pH of the human body must be between 7.3 and 7.8, otherwise the body is subject to very high risks, such as coma and tetanus.

Complete recovery from chronic disease occurs only when and if the blood is restored to a normal slightly alkaline pH value.

All biochemical and electrical energy reactions corresponding to life are controlled by pH. Body pH affects everything.

The pH controls everything: the brain, the heart, the enzymatic processes of the body, the assimilation of minerals in the body.

Pasteur promoted the theory of monomorphism: disease is caused exclusively by germs or bacteria that invade the body from the outside.

Béchamp asserted the theory of polymorphism: disease comes from within the body.

CLAUDE BERNARD launched the idea that disease in the body, as a biological process, will be developed and will depend on the internal biological state and the manifest terrain. The basis of this field is pH.

Pasteur eventually recognized Béchamp's work and said, "Bernard was right: the microbe is worth nothing, the environment is everything."

CHEMICAL ECHILIBRIUM

A series of chemicals are in equilibrium if the chemical composition of the species, temperature, and pressure are constant. Steady state does not mean that nothing happens inside this set. On the contrary, there is a lot going on!

Example : **$3H_2(g)+N_2(g) \leftrightarrow 2NH_3(g)$**

Hydrogen molecules react with nitrogen to form ammonia.

At the same time, the ammonia molecules break down into hydrogen and nitrogen.

There are many factors that influence the chemical equilibrium temperature, pressure, and concentration of the species in equilibrium. To explain how chemical equilibrium is influenced by these factors, we state

Le Chatelier's principle: if a constraint acts on a system in equilibrium, the system will react to alleviate this constraint.

If we act to raise the temperature, the system will react to lower it. The balance will be shifted towards the heat to be consumed, i.e. towards the endothermic reaction.

If we act to increase the concentration of a compound, the balance shifts toward consumption of that compound. Thus, if we add hydrogen to the chemical reaction above, the equilibrium shifts to the right because it is the reaction that consumes hydrogen.

If we act on an unbalanced system by increasing the pressure, it moves to the side where there are fewer gas moles.

For example, the reaction above. If the pressure increases, the equilibrium shifts to the right (there are only two moles of gas, as opposed to the left, where there are four).

THE LAW OF MASS ACTION

The law of mass action applies as follows:

All systems at constant pressure and temperature tend to reach a minimum free enthalpy G.

If during a reaction between ν1 moles of a substance A1 and ν2 moles of a substance A2, we obtain ν3 moles of a substance A3 and ν4 moles of substance A4:

$$\upsilon 1A1 + \upsilon 2A2 \leftrightarrow \upsilon 3A3 + \upsilon 4A4$$

Such a **reversible chemical reaction is a forward reaction** in which the substances react to give products **and a reverse reaction** in which the products recombine to give the initial products which progress to a state of dynamic equilibrium. The state of dynamic equilibrium is reached when the forward or reverse reaction rates become equal. Dynamically both opposite processes continue.

The state of dynamic equilibrium is characterized by: the equilibrium constant (K)

Where Kc - defined in terms of molar concentration

equilibrium constant (K) $K_c = \dfrac{c_4^{\nu 4} . c_3^{\nu 3}}{c_1^{\nu 1} c_2^{\nu 2}}$

according to the standard potential

$$K_c = e^{-\frac{\Delta G}{RT}}$$

$$\Delta G = \Delta H - T.\Delta S$$

$$\Delta G = \nu_3 G_{03} + \nu_4 G_{04} - \nu_1 G_{01} - \nu_2 G_{02} = \sum \nu_i G_{0i}$$

The free enthalpy of reaction ΔG is the function of the change in G when one mole of reactants is converted to products, provided that all concentrations of C1 = 1 mol/l.

Stoichiometric coefficients are positive (+) for reaction products and negative (-) for reactants.

ΔS is the entropy of the reaction

R = 8.31 J/mol.K. - Universal gas constant.

The equilibrium constant depends on the temperature:

$$K_c = e^{-\frac{\Delta H - T.\Delta S}{RT}} = e^{\frac{\Delta S}{R}} . e^{-\frac{\Delta H}{RT}}$$

- **ΔH is the enthalpy of reaction -** heat of reaction
- **ΔH < 0 exothermic reaction.** Increasing T shifts the equilibrium to the left.

- **ΔH > 0 endothermic reaction.** Increasing T shifts the equilibrium to the right

Generally it is used:

ci the molar concentrations of the substances dissolved in the solution,

pi partial pressures expressed in atmospheres,

xi mole fractions in solvated solvent mixtures.

Concentration is taken as ci = 1 for pure (unmixed) liquid and solid substances and for molecular solvent and in solution, the latter almost always in large excess.

In thermodynamics it is shown that physical transformations (dissolution, diffusion, osmosis) of substances tend to move towards a negative chemical potential.

Chemical potential μ_i corresponds to the free enthalpy content Gi of one mole of substance under the conditions of the concentration ci that is in the studied system.

m μ_{0i} is the standard chemical potential - it is the μ_i value for ci = mol/l

The more the concentration c_i decreases, the more μ_i decreases: substances pass from more concentrated solutions to more dilute solutions through the phenomenon of diffusion.

ACID AND BASE. ELECTROLYTE AND NONELECTROLYTE

In biology and medicine we work with aqueous solutions.

Water has a high dielectric constant ($\varepsilon r=80$) and the ability to solvate ions. Water promotes dissociation into ions.

Substances dissolved in water are called electrolytes and ion donors, and solutions containing ions are called electrolyte solutions.

Ions of H_3O^+ which will be further abbreviated as H^+ ions.

In water, it forms hydroxyl ions OH^-.

For any acidic or protonated form there is a conjugate base or deprotonated form.

Acid	**The conjugated base**
H_30^+	H_2O
H_2O	OH^-
NH_4^+	NH_3
CH_3COOH	CH_3COO^-

1. **Z. Simon, Cursory Note- Biophysics, Lito IMT, 1979.**
2. **Z. Simon, Fl. Rotemberg, Gh. I. Mihalas, Biophysics, Lito IMT, 1989.**
3. **A Neagu, M. Neagu, Biophysics Course for the Faculty of Dental Medicine, Ed. Eurobit, 2007.**

Strong electrolytes dissociate completely in aqueous solution.

Examples of strong electrolytes:

- all salts,
- strong acids (H_2SO_4, HCl, HNO_3)
- strong bases (NaOH, KOH)

Weak electrolytes dissociate partially. Most molecules are dissociated in aqueous solution.

Examples of weak electrolytes:

Weak acids (H_2CO_3, CH_3COOH)

Weak bases: ammonia (NH_3) and water (H_2O).

Non-polar solvents can be body lipids, membrane phospholipids.

They mainly dissolve non-polar and non-ionic substances.

Reactions of ions in aqueous solution at 37°C are fast reactions.

Acid-base systems and other systems that correspond to other ionic reactions in the body are in balance. This balance may vary from one compartment to another.

To deal with chemical and physical equilibria, the law of mass action is used.

The acidity or basicity of an aqueous solution is measured by pH or pOH

METHODS TO EXPRESSION CONCENTRATION

Mass concentration in percent: $C_{\%w/w} = \frac{m_d}{m}.100$

is the mass of the solute in 100 g of solution.

it is expressed in % or % w/w.

m_d = mass of solution, m = mass of solution

Volume concentration in percent: $C_{\%v/v} = \frac{V_d}{V}.100$

It represents the amount of solute in 100 ml of solution.

It is expressed in % vol or % v/v.

This concentration is used in alcoholic solutions.

When the volume of solution V_d, V the volume of solution

Molar concentration (C) - is the number of moles of solution in one liter of solution .

$$C = \frac{Vd}{V} = \frac{m_d(g)}{M_d(g).V(L)}$$

Normal concentration (CN) - the number of equivalents to dissolve in one liter of solution. It is expressed in eq/l or N. $C_N = \frac{Neq}{V}$

DISSOLUTION EQUILIBRIA. SOLUBILITY OF LIQUIDS AND SOLIDS

Dissolving a liquid and a solid in a solvent determines the equilibrium of the pure substance dissolved in the solution.

Apply the law of mass action:

A1 (pure) ⇆ A1 (solution): $c_1/1=k_1=s_1$

For the pure substance c = 1 has the role of solubility here.

Solubility product. STRONG electrolyte dissolution.

When a strong electrolyte is dissolved, it appears in solution as ions.

Apply the law of mass action to the dissolution of AgCl

$$AgCl(cristal) \Leftrightarrow Ag^{+} + Cl^{-} \ , \quad \frac{\left[Ag^{+}\right].\left[Cl^{-}\right]}{1} = k_{AgCl} = P_{AgCl}$$

Equilibrium constant: k_{AgCl} is called the solubility product P_{AgCl} .

Almost all biochemical reactions occur in aqueous solutions.

Some involve ions including OH^- and H^+ ions resulting from the decomposition of water.

A number of natural substances or drugs contain groups that can dissociate, and it is very important to know the electrical charge on the pH of physiological environments.

Protolytic reactions are reactions between acids and bases, from aqueous solutions, they are fast and a state of equilibrium is quickly established between the participants in these reactions.

DISSOCIATION OF WATER

The dissociation of water occurs in the stoichiometric equation:

$$H_2O \leftrightarrows H^+ + OH^-$$

Or more precisely: $2H_2O \leftrightarrows H_3O^+ + OH^-$

For simplicity, we consider H^+ the formula of the hydronium ion H_3O^+

Law of Mass Action:

$$\frac{[H^+]\cdot[OH^-]}{[H_2O]} = K \quad or \quad [H^+]\cdot[OH^-] = K = P_{H_2O}$$

Concentration of undissociated water = 1 as solvent.

Water dissociates very little, the dissociation constant or ion product of water is: $P_{H_2O} = 10^{-14}(mol/l)^2$

In the pure water (distilled) H^+ and OH^- ions come only from the decomposition of water and will be in equal amounts:

$$\left[H^+\right].\left[OH^-\right] = \sqrt{10^{-14}(mol/l)^2} = 10^{-7}\,mol/l$$

The water actually dissolves the CO_2 in the air and the silicate in the glass, so it is not pure.

DISSOCIATION OF ACIDS AND BASES

If a strong acid is dissolved, it is completely dissociated - practically all the H^+ ions come from the dissociation of the dissolved acid in water. The ionic concentration of product 2 remains constant $[H^+] \cdot [OH^-]$ = const. Thus, the $[OH^-]$ concentration decreases.

If a solid base dissolves, it is completely dissociated - the concentration of OH^- ions will equal the concentration of the base and decrease the concentration of dissolved H^+ ions.

Acidic aqueous solution is an aqueous solution in which :

$[H^+] > [OH^-]$ and a pH <7

Basic aqueous solution is an aqueous solution in which

$[H^+] < [OH^-]$ and a pH > 7

Neutral aqueous solution is an aqueous solution in which

$[H^+] = [OH^-]$ and pH = 7

Example: gastric juice has the pH = 1.5. What concentration of HCl does it contain?

For pH=1.5 we have $[H^+]=10^{-1.5}$ mol/l or log $[H^+]$=2.5

From the tables: $[H^+]$ = 0.0032 mol/l.

Since HCl acid is the single strong acid found in high concentrations in the gastric juice, then all $[H^+]$ ions **arise from its dissociation and the concentration of HCl is c = 0.0032 M = 32 mM.**

If we consider a weak acid HA that dissociates only partially, then:

$$HA \Leftrightarrow H^+ + A^- \quad , \quad K_{HA} = \frac{\left[H^+\right].\left[A^-\right]}{[HA]}$$

where K_{HA} is the acid dissociation constant

If we have no other acids or HA acid salts in the solution, as water dissociates very little, practically all ions come from HA dissociation.

As in the case of the dissociation of the HA molecule, we obtain an H^+ ion and an A^-

Thus $\left[H^+\right] = \left[A^-\right]$

A weak acid dissociates a little (in not too low concentrations).

The concentration of undissociated acid is in this case equal to the total acid concentration.

Thus: $\left[H^{+}\right]=\left[A^{-}\right], \quad \frac{\left[H^{+}\right]^{2}}{[HA]}=K_{HA}$

$$\left[H^{+}\right]=\sqrt{K_{HA}.[HA]}$$

Biological solutions usually contain many components and have a pH that remains constant due to so-called buffer systems.

What is the relationship between the protonated and the deprotonated form ?

$$\frac{[A^{-}]}{[HA]}=\frac{K_{HA}}{[H^{+}]} \quad , \quad \log\frac{[A^{-}]}{[HA]}=\log K_{HA}-\log[H^{+}]$$

$$p_{K_{HA}}=-\log K_{HA}$$

$$pH=-\log[H^{+}]$$

$$\log\frac{[f.deprotonated]}{[f.protonated]}=\log\frac{[A^{-}]}{[HA]}=pH-pK_{HA}$$

pH = pK $_{\mathbf{HA}}$ if the concentration of the deprotonated (dissociated) form (A) is equal to the concentration of the protonated acid form (undissociated) HA.

In more acidic solutions pH < pK$_{\mathbf{HA}}$ the protonated form predominates

In more basic solutions: pH >pK$_{\mathbf{HA}}$ the deprotonated form predominates

(Z. Simon, Fl. Rotemberg, Gh.I. Mihalas, Biophysics, Lito IMT, 1989)

DISSOCIATION OF ACIDS AND WEAK BASES. Examples

1. For a difference pH-P$_{KA}$ =1 , the ratio [A^{-}]/[HA]=10^{1} =10, the acid is 90% in its deprotonated form. 1 unit of the difference between pH and pKa means an almost total transition of the acid to its deprotonated or protonated form.

2. For example, blood has a pH of 7.4. What is the concentration of the deprotonated form CH$_3$COO$^-$ and protonated CH$_3$COOH from acetic acid?

First we calculate the pKCH_3COOH:

$$pK_{CH_3COOH}=-\log 2.10^{-5}=-\left(\log 2+\log 10^{-5}\right)=-(0,3-5)=4,7$$

$$\log\frac{\left[CH_3COO^{-}\right]}{[CH3COOH]}=pH-p_{KCH_3COOH}=7,4-4,7=2,7$$

$$alors \quad \frac{\left[CH_3COO^{-}\right]}{[CH3COOH]}=10^{2,7}=500$$

Acetic acid is completely dissociated at pH from the cellular environment, and all carboxyl groups (-COOH) are free.

THE CONCEPT OF pH

Electrolytic dissociation is a phenomenon in which certain substances in solution separate into positive ions and negative ions.

During the dissociation of an acid, hydrogen ions and acid radical ions appear: $AH \Leftrightarrow A^- + H^+$

During the dissociation of an acid, hydroxil ions and basic radical ions appear:

$BOH \Leftrightarrow B^+ + OH^-$

Water acts as an electrolyte and dissociates into hydrogen ions and oxydryl ions. $H_2O \Leftrightarrow H^+ + OH^-$

In reality, the hydrogen ion H^+ obtained after dissociation becomes hydrated and the equilibrium relationship will be written: $2HOH \Leftrightarrow H_3O^+ + HO^-$

The ion H_3O^+ is called hydronium.

The two-way arrow indicates that water molecules are ionizing and constantly renewing these ions. If the temperature is constant, the rate of recovery and ionization of the molecules remains constant, producing a steady-state concentration of H^+ equal to that of OH^-.

The process of dissociation is subject to the law of mass action

The resulting ratio of the product of the concentration of dissociated molecules to that of ions is constant.

$$K = \frac{C_{H}^{+} C_{OH}^{-}}{C_{H_2O}} = 1{,}8.10^{-16}$$

Ion concentrations are extremely low compared to the concentration of undissociated molecules. The concentration of non-ionized molecules can be considered constant.

The molar concentration of undissociated water molecules is 55.56 - grams for a volume of 1 liter.

The term $K.CH_2O$ is called the ion product of water and has a value of 10 to 14 for water temperature of 25°C and decreases if the water is cooled and vice versa.

$$C_{H}^{+} C_{OH}^{-} = K.C_{H_2O} = K_{H_2O} = 1{,}8.10^{-16}.55{,}56 \cong 10^{-14}$$

If we dissolve a strong acid in water, the concentration of hydronium ions H^+ increases and that of hydroxyl ions OH^- decreases because the ionic product of water remains constant at a given temperature.

If a strong base is dissolved in water, the concentration of OH^- increases, that of H^+ decreases.

At constant temperature, the concentrations of H^+ and OH^- can vary as follows:

CH^+	**10^0**	**10^{-1}**	**10^{-2}**	**...**	**10^{-7}**	**...**	**10^{-12}**	**10^{-13}**	**10^{-14}**
COH-	**10^{-14}**	**10^{-13}**	**10^{-12}**	**...**	**10^{-7}**	**...**	**10^2**	**10^1**	**10^0**
character	acidity			neutrality		alkaline			

To simplify the calculations, the expression agreed to present this concentration is :

The pH which represents the logarithm of the hydrogen ion concentration with a change of sign: H = -log H^+ or in general,

according to SORENSEN: pX = -log X =log (1/X) .

Or we can write: pH + pOH = pK, where pK is the ion product of water

pH	**0**	**1**	**2**	…	**7**	…	**12**	**13**	**14**
pOH	**14**	**13**	**12**	…	**7**	…	**2**	**1**	**0**
character	acidity				neutrality	alkaline			

The acidic or basic character of a solution can be described quantitatively in terms of the concentration of hydrogen ions. In some cases, where the concentration is very small, it is more practical to use the concept of pH.

pH is, by definition, the signed decimal logarithm of the molar concentration of hydronium ions:

The pOH of the solution is

The relationship between the two is: pH + pOH = 14

pH and pOH are complementary.

It is enough to indicate the pH to know if a solution is acidic or alkaline:

- if **pH < 7** - the solution is acidic
- if **the pH = 7** – the solution is neutral
- if **the pH > 7 -** the solution is basic (or alkaline)

pH SCALE

H+	**10^{0}**	**-**	**10^{-7}**	**-**	**10^{-14}**
pH	0	-	7	-	14
pOH	14	-	7	-	0
character	acidity		neutrality	alkaline	

Neutral solution is a solution in which the concentrations of H^+ and OH^- ions are equal and therefore **pH = 7.**

When water dissolves in a strong acid, the latter completely dissociates into ions, the H^+ ions coming practically only from ionization of the acid. The ionic product of water remains constant, the increase in the concentration of H^+ ions remains constant and the decrease in the concentration of OH^- ions, the sector **where pH < 7 is acidic**

If a strong base is dissolved in water, OH^- ions will come exclusively from this ionization, the concentration of OH- ions will prevail.

The basic sector is where the concentration of OH^- ions is higher, therefore pH > 7.

ELECTROLYTES AND NON-ELECTROLYTES

ACID		**BASES**	
Strong acids	**Weak acids**	**Strong bases**	**Weak bases**
SOLID INORGANIC ACIDS nitric acid, HNO_3 hydrobromic acid, HBr hydrochloric acid, HCl hydrochloric acid, $HClO_3$ hydroiodic acid, HI	**WEAK AND MEDIUM STRENGTH INORGANIC ACIDS** boric acid, H_3BO_3 carbonic acid, H_2CO_3 (simply called "acid" when included in mineral waters or soft drinks such as Fanta)	NaOH KOH LiOH $Ca(OH)_2$ $Ba(OH)_2$	Ammonia NH_3 H_2O $Mg(OH)_2$ $Zn(OH)_2$ $Al(OH)_3$

perchloric acid, $HClO_4$ sulfuric acid, H_2SO_4	hydrofluoric acid, HF phosphoric acid H_3PO_4 **WEAK ORGANIC ACIDS** acetic acid, CH_3COOH butyric acid, $CH_3CH_2CH_2COOH$ benzoic acid, C_6H_5COOH citric acid, ($C_6O_7H_8$) formic acid, HCOOH lactic acid, $CH_3CHOHCOOH$ malic acid, $HOOCCH_2CHOHCOOH$ oxalic acid, HOOCCOOH pyruvic acid, CHCOCOOH propionic acid, CH_3CH_2COOH valerianic acid, $CH_3(CH_2)_3COOH$		

Ionic forms of electrolytes are dissolved in water

All salts are weak electrolytes:

NaCl, CH_3COONa

Non-electrolytes are substances that are dissolved in water and do not dissociate:

Glucose: $C_6H_{12}O_6$

Urea: NH_2CONH_2

ELECTROLYTES AND NON-ELECTROLYTES.

CALCULATION FORMULA FOR pH

For strong acids: $\mathrm{pH} = -\lg\left[\mathrm{H}^+\right] = -\lg[\mathrm{HA}] = -\lg c$

For weak acids: $\mathrm{pH} = \mathrm{pK}_{\mathrm{HA}} + \lg\frac{[\mathrm{D}]}{[\mathrm{P}\ ]}$

The Henderson Hasselbach formula

D-deprotonated form, P-protonated form

For strong bases: $\mathrm{pH} = 14 - \mathrm{pOH} = 14 + \lg\left[\mathrm{OH}^{-}\right]$

The pH of STRONG ACID solutions:

According to Le Chatelier's principle, when a system in chemical equilibrium is disturbed by a change in temperature, pressure, and concentration, the system changes composition in a way that tends to counteract the variation parameter.

Applying this principle to the dissociation of water, we can say that in an acidic solution water contributes little to the release of H^+ ions.

By dissolving an acid in water, the water dissociation reaction is reversed: $2H_2O \leftarrow H_3O^+ + OH^-$ until a new equilibrium state is reached.

Therefore, the H^+ ion concentration of water resulting from autoionization is very low compared to that provided by acid dissociation. This is not true in very dilute solutions of strong acid, where the amount of H^+ ions results from the dissociation of water and is comparable to that provided by the acid.

Initial	**[HA]=c**	**0**	**0**
final	0	**$[H^+] = c$**	**$[A^-]= c$**

For a strong acid (HA), which dissociates completely in solution, the resulting ion concentration is determined by the stoichiometry of the reaction from the initial acid concentration.

$$\mathbf{HA \rightarrow H^+ + A^-}$$

For solutions of strong acids, the pH is calculated from the definition of the formula:

$$\mathrm{pH} = -\lg\left[\mathrm{H}^{+}\right] = -\lg[\mathrm{HA}] = -\lg c$$

Examples of strong acids: $HClO_4$, H_2SO_4, HI, HBr, HCl, HNO_3, etc.

pH OF STRONG BASE SOLUTIONS

For calculating the pH of strong bases, it is preferable to work with the complementary value of pH, namely pOH.

A base dissociation reaction has the form:

$$BOH \rightarrow B^+ + OH^-$$

Because OH^- ions basically result from dissociation of the base, except in very dilute solutions. In this case, it is also necessary to take into account the concentration of H^+ ions resulting from the autoionization of water.

The pH of the solution is calculated using the formula:

$$pH = 14 - pOH = 14 + \lg\left[OH^-\right] = 14 + \lg[BOH]$$

Examples of strong bases: LiOH, NaOH, KOH, $Ca(OH)_2$, $Ba(OH)_2$ etc.

pH OF WEAK ACIDS AND BASES

A weak acid is an acid that ionizes incompletely in solution.

Its molecules keep their protons, thus not all of them are transferred to water molecules to form H_3O^+ ions.

During the dissociation process of a weak acid HA:

$$HA \Leftrightarrow H^+ + A^-$$

After a while, the chemical reaction reaches a state of equilibrium, characterized by the fact that the rate of the acid dissociation reaction is adapted to the rate of recombination of H^+ and A^- ions to form the starting acid. From this point, the concentrations of reactants and reaction products remain constant.

The equilibrium constant of the dissociation reaction, according to the law of mass action:

$$K_{HA} = \frac{\left[H^+\right].\left[A^-\right]}{[HA]_{ech}}$$

This is called the dissociation constant or acidity constant of the acid.

$[HA]_{ech}$ - is the acid concentration upon reaching the equilibrium state corresponding to the dissociation reaction

Since dissociation of the acid occurs to a small extent, its concentration can be estimated to be similar to the initial concentration of the acid [HA]

Two pH formulas are used to calculate the pH of weakly basic and acidic solutions: $K_{HA} = \frac{\left[H^+\right]^2}{[HA]}$

When only the initial concentration of the weak acid is known, because H^+ ions and A^- dissociation results are found in solution in equal concentrations, the equilibrium constant becomes:

After logarithmization we obtain: $-\lg K_{HA} = -\lg\left[H^+\right]^2 + \lg[HA]$

Similar definition of pH: pH= -lgK.

The formula for calculating pH is: $pH = \frac{pK_{HA} - \lg[HA]}{2}$

When the concentration of the protonated form is known

[P] = [HA] - weak acid molar concentration

and the concentration of the deprotonated form

[D]= [A⁻] - the molar concentration of the conjugated base

We use **the HENDERSON HASSELBACH formula:**

$$pH = pK_{HA} + \lg\frac{[D]}{[P\ \ ]}$$

Carbonic acid H_2CO_3 has two stages of dissociation:

H_2CO_3 $\Leftrightarrow HCO_3^- + H^+$

$HCO_3^- \Leftrightarrow CO_3^{2-} + H^+$

$Ka_1 > Ka_2 > Ka_3$

Phosphoric acid H_3PO_4 has three stages of dissociation :

H_3PO_4 $\Leftrightarrow H_2PO_4^- + H^+$

$H_2PO_4^- \Leftrightarrow HPO_4^{2-} + H^+$

$HPO_4^{2-} \Leftrightarrow PO_4^{3-} + H^+$

These are called polybasic or polyprotic acids: H_2CO_3, $H_2C_2O_4$, H_3PO_4

A characteristic of these acids is that, independent of their strength in solution, they donate protons in steps, each step having a constant value of defined acidity.

Substance	**Chemical formula**	**pKa** **Dissociation constant**
acetic acid	CH_3COOH	4.8
carbonic acid	H_2CO_3	6.4
		10.3
oxalic acid	$H_2C_2O_4$	1.25
		4.3
phosphoric acid	H_3PO_4	2.2
		7.2
		12.3

The dissociation constant for the dissociation of polyprotic acid for the first stage Ka_1 is greater than Ka_2, corresponding to the second stage of dissociation which is greater than Ka_3, corresponding to the 3rd stage of dissociation : $\mathbf{Ka_1 > Ka_2 > Ka_3}$

The first proton is released more easily than the others

In the case of H_2SO_4 –the first proton represents a strong acid ($K_1 > >1$) and its conjugate base (HSO_4^-) is a light to weak acid ($K_2 = 1.2 \cdot 10^{-2}$)

For solutions of weak bases

the pH calculation is similar, using the base dissociation constant Kb.

Ka is the dissociation constant of the weakly conjugated acid.

$$HA + H_2O \Leftrightarrow H^+ + A^- \quad , \quad K_a = \frac{[H^+].[A^-]}{[HA]}$$

$$A^- + H_2O \Leftrightarrow HA + OH^- \quad , \quad K_b = \frac{[HA].[OH^-]}{[A^-]}$$

$$K_{a.}.K_b = P_{eau} = 10^{-14} M^2 \quad et \quad pKa + pKb = 14$$

THE BUFFER SYSTEM

It is named buffer system, those solutions that are able to maintain constant pH even with the addition of limited amounts of acid or base.

Buffer systems have the following composition:

- a weak acid and its salt
- a weak base and its salt

The calculation of the pH of a buffer system is done using

Henderson-Hasselbach formula:

$$pH = pK_a + \lg\frac{[D]}{[P]} = pK_a + \lg\frac{[concentration\ of\ deprotanated\ form]}{[concentration\ of\ protanated\ form]}$$

Biological fluids – blood – contain buffer system

pH control is vital for their proper functioning.

For blood the pH = 7.4

Blood buffer systems: **H_2CO_3 and HCO_3^- ; $H_2PO_4^-$ if HPO_4^{2-}** acid hemoglobin and potassium hemoglobinate.

Disorders incompatible with life.

Increasing the concentration of H^+ ions by lowering the pH below 7.1 = acidosis

Decrease in the concentration of H^+ ions with increasing pH values above 7.8 = alkalosis

Consider a buffer system consisting of a weak acid and its salt.

The strong acid added to such a buffer system removes some of the weak acid from the salt, leading to changes in the concentrations of the protonated (weak acid) and deprotonated forms (anions resulting from dissociation of the salt).

If a strong base is added to a buffer system, it reacts with the weak acid, thereby reducing the concentration of the protonated form and increasing the concentration of the deprotonated form.

Consider a buffer system comprising a weak base and its salt

If you add a strong acid, it reacts with the base.

When a strong base is added, it will remove some of the weak base from the salt, the result is the same: changes in the deprotonated and protonated concentrations.

When the strong acid/base is added in limited quantities, one of the components of the buffer system is completely consumed, as a result of the chemical reaction that takes place and results in the loss of buffer capacity.

An important characteristic of the buffer system is *the buffer capacity (i)*

$i = \frac{\Delta V}{\Delta pH}$ **- it represents the amount of acid or base that, after being added to the solution, changes its pH by one unit.**

The buffering capacity is optimal when dissolving the buffer in media with a pH close to pK (where the concentrations are protonated and deprotonated, respectively, of comparable order of magnitude).

Example:

- The system composed of CH_3COOH and CH_3COONa is a good buffer in solutions with a pH = (4.2-5.4)
- In conditions where the pH of the body is pH=(7.1-7.8), the concentration of the protonated form is 1000 times lower than that of the deprotonated form, so the buffering capacity is very low.

The pH of the extracellular and intracellular compartments

For the extracellular environment: pH = 7.4

Water does not contribute to proton exchange when an acid or base is added to the extracellular fluid.
Variations in arterial blood pH in the venous interstitial space occur.
During exercise, there is a drop in muscle bulk pH by a factor of 6.9 due to the production of lactic acid by anaerobic glycolysis.

For the intracellular environment pH = 6.9 under normal conditions

It can vary from one cell type to another
intracellular pH changes can occur in pathological cases:
in acute ischemic infarction the cellular pH may drop to 6.64 especially during alkalosis.

The approximate pH of body fluids

the extracellular environment	**arterial blood**	**7.4**
	venous blood	7.35
	interstitial fluid	7.35
the intracellular environment	heart muscle	7.1
	skeletal muscle	6.9
	liver cells	7.23
	erythrocytes	7.28
secretions	gastric juice	1.8
	urine	5.6
	pancreatic juice	8

THE BIOMEDICAL IMPORTANCE OF pH FOR THE HUMAN BODY

Complete recovery from chronic disease occurs only when and if the blood has a normal pH value: slightly alkaline pH.
Body pH affects everything.
Human blood stays within a very narrow pH range around 7.3.
Lower or higher values indicate symptoms and disease.
When the pH rises, the microbial forms of the blood can alter the mutations that occur
As the pH rises, enzymes that are constructive can become destructive.
When the pH rises, the oxygen supply to the cells suffers.
Research shows that low oxygen supply to cells is a major factor in most, if not all, degenerative conditions.

Dr. Otto Warburg of Germany won the Nobel Prize for discovering oxygen deficiency in the growth of cancer cells.
When the pH drops and our body becomes more acidic, our cells receive less oxygen.
Cancer thrives in an acidic pH and tissue/oxygen deficient environment. No wonder cancer rates are up today
As a reminder of the importance of oxygen in life, think about what happens if we stop to breathe for a minute.
Each cell in the body may or may not respire completely.
It depends on whether it has an optimal pH balance
(http://biomedx.com/microscopes/rrintro/rr4.html)

pH controls everything:
Like the brain that needs fuel to function, where the fuel is glucose. However, unlike other cells, the brain cannot store glucose. It depends on how the blood supply is affected by pH, which controls the effectiveness of insulin and allows sugar to enter cells; therefore it controls blood sugar levels.
According to William Philpott's "Biomagnetic Handbook", **in the case of the heart** there was a connection between the pH of the body and the electrical side of the human body.
If the pH of the blood becomes more acidic, the fatty acids that normally have negative electromagnetic charges become positive and are automatically attracted to and begin to stick to the walls of the arteries, which are electromagnetically negative. Eating too much that could cause the blood to be more acidic will lead to a higher rate of heart disease.

Enzymes are part of the biochemical process. There are hundreds if not thousands of enzymatic processes that take place in the body. Many are so specific. When the pH of the blood is out of balance, enzyme function changes and the body begins to suffer.

Mineral absorption is affected by pH .

Minerals have different pH levels at which they can be assimilated in the body.

Low molecular weight minerals can be absorbed over a wider pH range, and high molecular weight minerals require a narrow pH range to be absorbed by the body.

Exemples:

Sodium and magnesium have wide ranges for pH assimilation.

The ranges narrow slightly for calcium and potassium.

The ranges are further reduced for manganese and iron.

The ranges are further reduced for zinc and copper.

The ranges narrow much more for iodine.

Iodine, which is at a very high position on the atomic scale, requires an almost ideal pH for its assimilation in the body.

Iodine is one of the most important minerals for the proper functioning of the thyroid gland. But the thyroid has no access to iodine unless the body's pH is close to perfect.

- Liquids such as blood contain buffer solutions to control pH, which is vital for their proper functioning. Buffers such as: H_2CO_3 and HCO_3^- and $H_3PO_4^-$ and HPO_4^{2-}, acid hemoglobin and sodium hemoglobinate play a very important role in keeping the pH constant in the 7.35-7.45 range.

The increase in the concentration of H^+ ions and the simultaneous decrease in pH (values below 7.1) is known as acidosis.

The decrease in the concentration of H^+ ions resulting in an increase in pH (values above 7.8) is called alkalosis.

Enzymes that play an important role in many biochemical reactions that occur in the body are each activated at a specific pH value.

The pH changes that occur in various diseases lead to the disruption of the normal functions of these enzymes and the metabolic processes involved.

Examples:

- Blood pH drops sharply during diarrhea, ulcerative colitis, diabetic acidosis, renal failure, etc.

- **Blood pH rises sharply** in pyloric stenosis in repeated vomiting and various nervous disorders.
- **Physiological changes in the pH of body fluids and tissues may also occur.**

For example, at high altitude, through hyperventilation, there is an increase in blood pH (the partial pressure of CO_2 decreases in the blood). Following intense activities; there is an accumulation of lactic acid in the muscles which causes a drop in pH - and that is why muscle cramps occur -.

The esophageal pH meter is an examination that helps diagnose gastroesophageal reflux (abnormal passage of stomach acid into the esophagus). It also allows controlling the effectiveness of a surgical or medical treatment of this disease.

The normal value of urine pH is between 4.5 and 8.

A very pronounced acidity of urine occurs in acidosis, diabetes, diarrhea, dehydration, while pronounced alkalinity is characteristic of urinary tract obstruction, pyloric obstruction, chronic renal failure.

Certain substances contained in the administered drugs can change the pH of the urine,

Examples:

- *potassium citrate, sodium bicarbonate* , which **leads to an increase in pH (alkaline urine)**
- *ammonium chloride or some diuretics* **cause a drop in pH (acidic urine)**

DISPERSED SYSTEMS

CLASSIFICATION OF DISPERSED SYSTEMS

Dispersed systems are applied to systems comprising a continuous, homogeneous and isotropic medium called the dispersion medium and a discontinuous medium called the dispersed phase.

The dispersed system is a heterogeneous system.

For a solution, the solvent is a dispersion medium, the solute - dispersed phase

Colloidal systems are microheterogeneous systems or dispersion systems with a very large surface area of the interface between two phases, so surface tension energy and adsorption phenomena play an important role in determining the properties of the system.

Living systems, cells with their macromolecule solution systems, and biological membranes exhibit the properties of colloidal systems.

The degree of dispersion is the inverse of the size of the phase (particles) dispersed in a dispersion medium. The smaller the particle size, the larger the interfacial area. The surface area S of the interface increases proportionally to the cube root of the number N of particles.

1. Depending on the particle size of the dispersed phase

- **Molecular solutions** are obtained by dissolving micromolecules (molecular mass M <1000), particle size: $\phi < 10 Å\ (10^{-9})$

- **Colloidal solutions** with particle sizes between 10 and 1000 Å.

$$10^{-9}\ m < \phi < 10^{-7}\ m.$$

- **Macroparticles** *with* $M > 10^3 - 10^4$ *they are particles* that, upon dissolution, give colloidal solutions. They have characteristic properties such as coagulation.

- **Suspension – particles are larger than** $1000\ Å, \phi > 10^{-7}\ m$

Particles dispersed in suspension settle and settle (or rise to the surface) under the influence of gravity.

2. Depending on the dispersion medium and dispersed phase

3. Depending on the number of dimensions that are microdispersed

- If the three dimensions are microdispersed are between 10 and *1000 Å* : we have adequate solutions.
- If two dimensions are between 10 and 1000 Å, they are microdisperse systems and we have capillaries or filamentous molecules,
- If a single dimension is between 10 and 1000 Å – we have membrane systems.

Classification of distributed solutions and systems:

Depending on the dispersion medium and the dispersed phase:

Dispersion medium	**dispersed phase**	**Name**
gas	liquid	fog aerosols (clouds)
	solid _	smoke (dust)
liquid	Gas	foam
	liquid	lyosol emulsion
	solid	suspension
solid	Gas	solid foam
	liquid	capillary systems of the soil
	solid	glasses and alloys

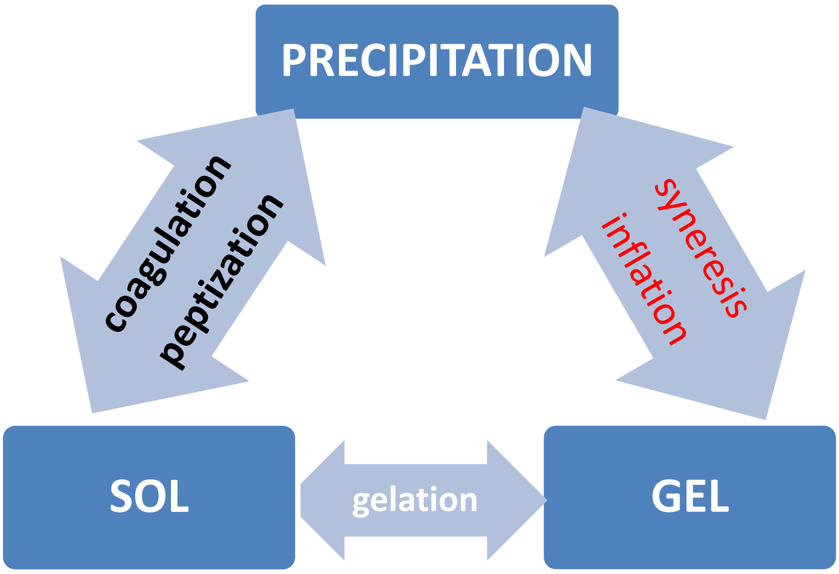
SOL-GEL TRANSSITION

The colloidal solution itself, with the characteristic properties of a liquid, is called SOL. Under certain conditions, soil gels, an intermediate state between liquid and solid, it does not flow, is elastic at small deformation, however it is plastic at large permanent deformation. It allows the diffusion of micromolecular substances but does not allow convection. It is a good medium for chemical reactions and it allows electrical conductivity by ions.

The transition between sol and gel is made by the passage of part of the solvent and vice versa, by absorption or by mechanical agitation.

Through syneresis – which means the loss of most of the solvent – **the gel is transformed into a precipitate.**

The precipitate has the usual properties of amorphous or crystalline solids, a much smaller volume than the gel, and prevents diffusion or other related phenomena.



COAGULATION is the reduction of dispersion to form large particles that settle to form a precipitate.

In the case of gelation, the particles come together to form a loose network in which the solvent is located.

CYTOPLASM, due to the nature of the substances dispersed in the solution, is at the same time a molecular solution (salts), a colloidal solution (proteins) and a suspension (organs: mitochondria, ribosomes).

In terms of mechanical properties , the fact that droplets of protoplasm tend to coalesce, flow out of the membrane pores to allow convection currents to redistribute the cytoplasm into the liquid (ground) interval **.**

Its very low elasticity and tendency to flow brings it close to the gel state.

This intermediate state of the cytoplasm between soil and gel is due to a loose network of filamentous protein molecules with contact points between the cytoskeleton and the microtrabecular network.

According to the way in which a substance passes through a semipermeable membrane:

- **Crystalloids** (crystals formed after solvent evaporation)
- **Colloids**, after evaporation of the solvent remains a sticky film that cannot be dissolved.

The classification of substances into colloids and crystalloids is arbitrary because in general a substance can exist both in colloidal and crystalloid form depending on the dissolution and separation conditions.

Examples:

- NaCl is a typical crystalloid which under normal conditions forms a colloidal solution in benzene

- The soap forms a colloidal solution in water but has crystalloid properties in alcohol.

CLASSIFICATION OF COLLOIDAL SYSTEMS

By colloids we do not currently understand a certain class of substances, but a certain state of the substance to which certain of its characteristic properties refer.

Today, instead of colloidal solutions, the notion of **colloidal system is used** .

Depending on the structure of the colloidal particles, colloids can be divided into three categories:

- **Dispersion colloids**
- **Association colloids - or micellar colloids**
- **Macromolecular colloids**

The micelle is a nearly spherical particle composed of amphiphilic molecules that have polar ends facing outwards and apolar - hydrophobic ends facing inwards. An example of a micellar solution is soap in water.

Macromolecular colloids have primary interatomic bonds (eg proteins, starch).

According to the shape of the molecules we distinguish:

Linear colloids consist of chains and exhibit high mechanical strength and viscosity. Structural proteins include myosin and fibrin.

Spherical colloids – **spheroids:** have lower viscosity and move easily

Colloidal systems are also classified according to the degree of dispersion.

The degree of dispersion D: expresses the degree of division of the substances that form the dispersed dose.

The degree of dispersion is an important criterion for the classification of physico-chemical systems which is defined as the inverse of the size d - the diameter of the dispersed particles:

$$\mathbf{D = 1/d\ (cm^{-1})}$$

The degree of dispersion D is the number of particles that could be placed next to each other at a distance of 1 cm.

	System	**d(cm)**	**D**	**Observations**
1	Systems with a low degree of dispersion	$>10^{-5}$	$<10^{5}$	Do not pass through fine paper filters. They do not dialyze. They are visible under an optical microscope
2	Systems with a degree of colloidal dispersion	$10^{-5} \div 10^{-7}$	$10^{5} \div 10^{7}$	Pass through the best filters. No dialysis No emissions They are visible under the ultramicroscope
3	Systems with a degree of molecular dispersion	$<10^{-7}$	$>10^{7}$	Pass through all filters Dialysis It is not visible to the ultramicroscope

Regarding aggregation status, the dispersion systems can be:

- Liquids (milk)
- Solids (some minerals)
- Gaseous (fog in atmosphere). In semi-liquid, semi-solid or semi-gaseous state, gels are formed.

Liquid colloidal systems are called colloidal solutions or sols.

Solutions in which the dispersion medium is water are called HYDROSOLES.

Colloidal solutions can be distinguished by the state of dispersion and the dispersed phase.

Each of them can be in solid, liquid or gaseous form.

Dispersion systems in which the dispersion medium is a gas are called AEROSOLS. Depending on the state of aggregation of the dispersed phase, aerosols are divided into

- smoke (if the dispersed phase is solid)
- mist (if the dispersed phase is liquid)

Systems in which gas bubbles are distributed in a liquid are called foams.

By the LYOPHILIC nature of the colloidal particles is meant their ability to bind very strongly and for a large number of molecules, the dispersion medium forms the solvation layers.

On the contrary, when the particles cannot interact so strongly with these molecules, we speak of **the LYOPHOBIC nature of the colloids**.

In the particular case of aqueous solutions, the terms hydrophilic and hydrophobic in nature are used in the same way.

Currently, the terms lyophilic or lyophobic are used in a broader sense of non-colloidal systems that characterize the ability of a substance to bind water or not.

LYOPHOBIC COLLOIDS are heterogeneous systems with a high degree of dispersion. This category is mainly composed of inorganic systems in an aqueous dispersion medium.

Upon separation from the dispersed phase, typical lyophobic colloids form powdery precipitates that do not contain significant amounts of dispersion medium.

Lyophilic and lyophobic character of colloids

- LYOPHOBIC COLLOIDS are characterized by irreversibility and from a thermodynamic point of view, the state of aggregation has no stability

-LYOPHILIC COLLOIDS are homogeneous systems whose particles bind large amounts of molecules of the dispersion medium, for example salts in an aqueous medium.

- **Lyophilic colloids are reversible** (dissolve spontaneously).

Dispersions in the class of lyophilic colloids consist of particles in which all atoms are bound together by covalent bonds. Therefore, each particle is a macromolecule.

Lyophilic molecular colloids include many organic substances with large molecules. Some form colloidal solutions in water (proteins, starch), others dissolve only in organic solvents (tires).

STABILITY OF COLLOIDAL SYSTEMS

Colloidal systems differ significantly from each other in terms of stability. Some can be stored for a long time, others are sensitive to various factors, being relatively stable.

There are two categories of processes that lead to the destruction of colloidal systems and that under certain circumstances can occur spontaneously.

Category 1: FLOCCULATION PROCESS or agglomeration process, in the form of larger particles (flakes), fine suspension particles or colloidal solution, followed by their precipitation under the action of a flocculant. In this category are the processes in which the particles of the dispersed phase can be separated by deposition or emersion at the surface of the liquid depending on the ratio between the density of these particles and that of the dispersion medium.

Category 2: COAGULATION PROCESS: **a process that consists in the growth of the particles of the dispersed phase after their fusion.**

THE STABILITY OF COLLOIDAL SYSTEMS IS CLASSIFIED AS FOLLOWS:

1. **KINETIC STABILITY**
2. **STABILITY OF THE AGGREGATION**

1. KINETIC STABILITY is related to the fact that **in colloidal systems, the sedimentation phenomenon opposes the thermal agitation of the dispersed particles (Brownian motion) caused by the collisions of the molecules of the dispersion medium and also by the middle and small dimensions of the particles.** For this reason in colloidal systems the particles are kept in suspension, even in the case of a significant difference between the densities of the dispersion medium and the particles of the dispersed phase.

2. AGGREGATION STABILITY - COAGULATION - explains the ability of a system to maintain its degree of dispersion. **Aggregation stability is determined by the existence of an electric charge and a solvation layer of the dispersed phase particles.**

STABILITY TO AGGREGATION – COAGULATION

In relatively stable colloidal systems after interaction with molecules or the electrical medium, the ions of the medium disperse the phase particles belonging to the medium in question.

This does not mean that the entire system is charged.

In general, the system is electrically neutral.

There are two main causes that determine the electrical charge of particles belonging to different species of colloids.

1. Some colloids (molecular) contain acidic or basic groups that can be ionized or form salts with small amounts of acids or bases in solution. The colloidal particle in this case is a macroion.

2. The electric charge of some colloids (suspensoids, molecular colloids and non-electrolytes) is due to the absorption of ions on the surface of the particles. This follows from the fact that the magnitude of the particle charges can be altered or the sign can be changed by adding electrolytes.

For example, colloidal silver iodide can precipitate as positively charged particles when a very dilute solution of KI is dropped into an excess of $AgNO_3$. Changing the charge of the particles produces a change in the degree of dispersion of the colloid.

In conclusion, changing the charge of the particles produces a change in the degree of dispersion of the colloid, changing the charge favors the growth of the particles.

STABILITY AND STRUCTURE OF COLLOIDAL SOLUTIONS

The stability of colloidal solutions is conditioned by two factors.

On the one hand, **surface tension tends to lower the interface** between the dispersed phase and the dispersion medium to minimize dispersion, thus producing coagulation.

On the other hand, **the electrical charge of the colloidal particles** produces a repulsion between them opposing the decrease in the degree of dispersion, thus stabilizing the sol.

Hydrophilic (usually lyophilic) colloids are those that have a low surface tension with respect to water. Their sols are stable and the tendency to coagulation is weak or completely absent. Some of the polysaccharides and proteins give such solutions, outside the colloidal particle are groups that give hydrogen bridges (a group -OH, -CO-NH-) or ionized ($-COO^-$, $-NH_3^+$).

Hydrophobic (usually lyophobic) colloids have high surface tension and tend to coagulate. Emulsified lipids during digestion have the most hydrophobic, non-polar groups on the surface, the solutions are stabilized.

The electrical charge of colloidal particles originates from ionogenic groups or from the preferential adsorption of ions with a particular sign.

Proteins have ionic and anionic and cationic groups - the COOH and $–NH_2$ groups of the side chains of monoaminodicarboxylic and diaminocarboxylic acids.

The total charge of the protein molecule will depend on the pH.

Particle structure of colloidal solutions

Unlike fixed charges that form a well-defined layer on the surface of the colloidal particle, water molecules are oriented and move with the particle forming a grain. Some of the counterions are in the bound water layer and thus, the charge has no charge, but charge [-(nx)e].

The layer of counterions in the rest of the solution is more diffuse, including the counterions of the so-called diffuse layer, in free water. What matters for the movement of the grain in an electric field is its charge [- (nx)e] is the electric potential at the boundary of the bound water layer called the electrokinetic potential (zeta).

Coagulation of the colloidal solution can be achieved by:

Bring the pH to pHi when the overall charge and kinetic potential cancel.

Salification: addition of soluble salts in high concentrations (1-5 M), for example: $(NH_4)_2SO_4$. By hydrating the salt ions, the amount of free water in the colloidal solution decreases and the colloid is deposited, increasing its effective concentration in the free water from the solubility of the dispersed substance. A water-soluble organic solvent (eg, ethanol) has a similar effect.

Addition of high valence ions produces coagulation, according to the Schulze-Hardy rule, with the increase in the valence of the ions, the concentration required to produce coagulation (the coagulation threshold) drops sharply. **For example: for a FeO (OH) sol** , the coagulation threshold is 9 mM for KCl, 0.2 mM for K_2SO_4 or $MgSO_4$. For As2S5 sol we obtain by using: 70 mM NaCl, 1 mM $MgCl_2$, 0.13 mM $AlCl_3$

Micellar solutions are substances with a surface-active character, detergents that, by dissolving in the form of a solution, form micelles if their concentration exceeds a certain threshold. **For example**, for salts of fatty acids with a polar part and a nonpolar chain (CH_3 -$(CH_2)_n$ -COO^- Na^+) if the concentration of the solution is higher than the micellar threshold, the concentration of monomer ions no longer increases and the monomers they combine the non-polar chains into a kind of oil droplets, carrying the polar groups. The surface tension lowering effect produced by the detergent reaches its upper limit when the detergent concentration reaches the micellar threshold.

PROPERTIES OF COLLOIDAL SOLUTIONS

Due to the intermediate size of the molecules of the dispersed phase located at the border between micro and macroscopic in colloidal solutions, the following physico-chemical phenomena can be observed:

- **BROWNIAN MOVEMENT**
- **COAGULATION**
- **THE EQUILIBRIUM OF SEDIMENTATION AND ULTRACENTRATION**
- **THE TYNDALL-FARADAY EFFECT**

1. Filtration: Colloidal solutions pass through plain paper filters. There are special filters that retain them.

2. Brownian motion: it consists in the chaotic, disordered motion of the particles of the dispersed phase inside the solution. Increasing the temperature will result in the intensification of this movement by increasing the velocity of the particles.

1. FILTRATION There are two main filtration techniques:

Frontal filtration, the best known, consists in the passage of the fluid to be filtered perpendicular to the surface of the filter. This is the technique used for example for coffee filters. As particles are retained by the filter, this technique is limited by the accumulation of particles on its surface, which gradually end up blocking it (clogging).

Tangential filtration on the contrary, consists in passing the fluid tangentially to the surface of the filter. It is the pressure of the fluid that allows it to pass through the filter. The particles, in this case, remain in the tangential circulation flow, and clogging is thus achieved much less quickly. However, this technique is reserved for filtering very small particles ranging in size from nanometer to micrometer.

We can also call the filtering operation differently depending on the filter pore size:

- clarification filtration: pore diameter greater than 10 µm
- microfiltration: pore diameter between 10 nm and 10 µm
- ultrafiltration: pore diameter between 1 and 100 nm
- reverse osmosis: pore diameter less than 1 nm

We speak of sterilizing filtration when the pore diameter is less than 0.22 µm (220 nm), allowing the retention of microorganisms.

3. COAGULATION occurs when pH=pHi (the pH of the solution and the pH of the macromolecules, the value at which their total charge is zero and therefore the electrostatic repulsion forces between them are canceled).

Adjusting the pH of a solution to the pHi value of a particular protein species is a method that allows the separation of the species from a protein mixture because it results in the coagulation of the species.

For example, the main protein in egg white is ovalbumin which is able to coagulate after heating.

4. THE SEDIMENTATION EQUILIBRIUM AND ULTRACENTRIFUGATION

In the gravitational acceleration field g, the particle density per unit volume decreases exponentially with height h.

For dispersions, emulsions and suspensions, the height h1/2, at which the particle density is halved, is small, but not for colloidal particles. Colloidal particles are in equilibrium in their solutions. In order for the colloidal particles to settle, the colloidal solution is introduced into the centrifugal acceleration field created in the ultracentrifuge.

Centrifugal force is written as follows: $F_{cf} = m.\omega^2 R = m.(2.\pi\nu)^2.R$

Centrifugal force causes the separation of colloidal particles from the solvent molecules, their migration to the centrifuge wall and sedimentation there.

The particle deposition rate v is proportional to the centrifugal acceleration ω^2 R : $v = \frac{dr}{dt} = s.\omega^2 R$

S is called the sedimentation constant.

The unit for the sedimentation constant is 1Svedberg = 10^{-13} s/rot^2.

For colloidal particles and the diffusion constant is inversely proportional to M$^{1/3}$.

$$M = \frac{R.T.s}{D\left(1 - \frac{\rho_L}{\rho_M}\right)} \quad if \quad M \approx s^{\frac{3}{2}}$$

ρ_L is the density of the solvent

ρ_M is the density of the substance

ULTRACENTRIFUGATION

it is used to determine the molecular mass of the colloidal particle and to separate cell organelles according to size - for example, the suspension obtained from cell trituration.

The separation of organelles follows the dimensions, namely:

nuclei, mitochondria, ribosomes and so on

Tyndall-Faraday effect: consists in strong lateral scattering of light in colloidal solutions.

The intensity of the scattered beam has the following formula: $I = I_0 \frac{n.K.V^2}{\lambda^\alpha}$

Or:

I = scattered beam intensity

I_0- intensity of the incident beam

K- Constanta

n - the number of particles per unit volume

λ- the wavelength of the light used

α- factor that depends on the size of the particles

We have the following cases:

α=4 if λ<<d (the diameter of the particle is much smaller than the wavelength used)

α=0 if λ=d (the diameter is of the same order of magnitude as the wavelength)

Note that for small particles are more strongly dispersed than small λ for large diameter colloidal particles, it does not depend on λ

ELECTROKINETIC PHENOMENA IN COLLOIDAL SOLUTIONS

1. Electrophoresis of proteins resides in the migration of macroions, under the action of the electric potential difference that is applied between two electrodes: the anode (+) and the cathode (-).

In such an electric field, the macroions move towards the opposite electrode. It is a method of determining the isoelectric pH of the protein, because in this case the macromolecule is electrically neutral and remains at rest.

Placed in an electric field of constant intensity, the protein macroion moves under the action of a constant electric force directly proportional to the apparent charge. Motion in the electric field resists friction due to the viscosity of the medium. When the two forces are equal, the particle reaches a constant speed limit called electrophoretic mobility. The migration rate is directly proportional to the total charge (Z), respectively directly proportional to the molecular weight.

In electrophoresis, the cause is the potential difference and the effect is the displacement of macroions in this field.

2. Dorn effect: consists in the appearance of a potential difference (effect) due to the movement in the gravitational field of electrically charged particles (cause). The effect can be revealed in a suspension of particles

negatively charged clay. After their sedimentation in solution, a potential difference appears which can be measured with a galvanometer.

3. Electro-osmosis: occurs as a result of macroions forming their water of hydration during electrophoretic movement, thus leading to a net transport of water molecules that can pass through them.

4. Flow potential: it is the reverse flow effect compared to electro-osmosis and consists in the appearance of a potential difference at the ends of a capillary, through which a liquid is forced. Its displacement involves the layer of counterions that agglomerate at the end of the capillary.

Preparation and purification processes of colloidal solutions

Preparation:

In contact with the solvent, protein macromolecules form colloidal solutions, interactions between solvent molecules and colloidal particles depending on the nature of the protein.

Lyophilic colloids (if the solvent is water, they are called hydrophilic) can be obtained by simply dissolving the colloidal particles in the solvent, because they have an affinity for them.

Lyophobic colloids (having water as a solvent, they are called hydrophobic) require other methods, since the colloidal particles cannot form bonds with the solvent molecules, the methods used include strong mechanical agitation, ultraforming to disperse or to use surfactants.

Preparation and purification processes of colloidal solutions

1. **Filtration**
2. **Ultrafiltration**
3. **Ultracentrifugation**
4. **Dialysis**
5. **Electrodialysis**

1. Filtration: is a physical process of selective retention of the components of a given substance passing through a suitable medium - filter paper with pores of 1.5-5 μm or parchment paper with pores of 0.2 μm or cellophane paper etc.

2. Ultrafiltration: under the effect of its own weight. The filters are made of collodion with pores of 10-200 nm).

3. Ultracentrifugation: it is another purification method.

It is made with a centrifuge at a very high speed of rotation with: 100,000-200,000 rotation/min. By centrifugation, the sedimentation rate is accelerated in proportion to the acceleration factor β:

$$\beta = \frac{\omega^2 x}{g}$$

And the sedimentation rate is: $V_c = \frac{2 .\omega^2 \left(\rho - \rho_0\right).r^2}{g.\eta}$

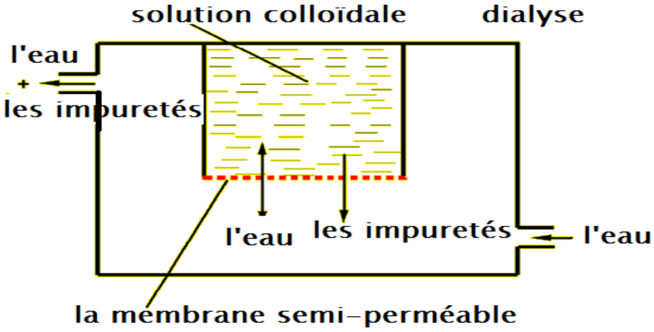
where ω^2 x = centrifugal acceleration, g-gravitational acceleration in free fall; x – the distance from the particles to the spin axis of the centrifuge and η and ρ_0 are the viscosity coefficient and the density of the medium, respectively in which the sedimentation takes place and ρ is the density of the particles with radius r.

Very fine suspensions and sedimentation colloids are separated by sedimentation, the centrifugal force can exceed a million times the force of gravity (~10^5 -10^6 g)

4. Dialysis is a process of purification of colloidal solutions of molecular dispersion based on the diffusion of macromolecules and microions through a semipermeable membrane.

The machine used for dialysis is called a dialyzer.

Under the effect of the concentration gradient between the two media, microions and micromolecules will cross the semipermeable membrane, then be entrained by water and removed from the system.



For example, extrarenal pathology using **extrarenal dialysis**.

The inability of the kidneys to perform their various functions in keeping the internal environment constant is known as **renal failure**.

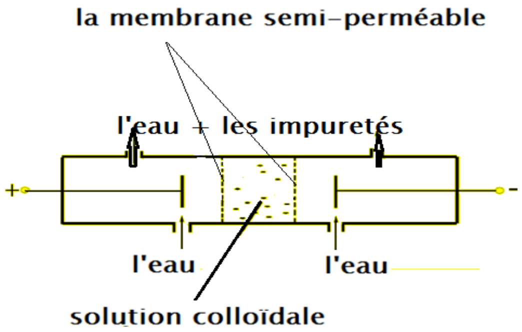
Blood nitrogen content above 0.1-0.15% is the result of a failure of the filtering function of the kidneys. This is mainly due to the accumulation of urea and uric acid and is therefore called **uremia**.

Extra renal dialysis is the separation of colloidal substances from crystalloid substances through a semipermeable membrane placed in a research solution and pure water or a solution of a given composition.

Extra renal dialysis refers to a physical process by which the blood of a patient suffering from renal failure is brought into contact with a hydro-electrolyte solution having a specific composition and is carried out through a semi-permeable cellophane membrane that allows the passage to both sides of water and small molecule substances.

Exchanges are based on the laws of osmosis. In the patient's body, the substances accumulated in excess in the blood will diffuse into the dialysis fluid through the cellophane tube. At the same time, the blood is enriched with substances whose concentration is weak compared to the dialysis fluid whose composition reproduces the extracellular fluid.

However, **intestinal dialysis and peritoneal dialysis** also exist.



permet l'élimination rapide des ions

PHENOMENA THAT TAKE PLACE AT INTERFACES

SURFACE TENSION

If at least one of the phases is a liquid, at the separation surface a force appears that tends to reduce the contact area between the phases and it is called **surface tension force.**

Due to this force, liquid droplets tend to have a spherical shape, because a sphere is the geometric body that has the minimum surface area for a given volume. The larger the shape of a body, the further from the sphere a given volume, the larger the surface.

For example, red blood cells have a biconcave disc shape and is approximated by a disc with a diameter of approx. D=4 μm with a volume of approx. V=80 μm^3 and an area of S=140 μm^2 ,. S/V= 1.75 μm^{-1} . If the red blood cells were spherical at the same volume, we would have: S/V=1 μm^{-1}.

Having large areas of separation between phases, living systems involve complex interfacial phenomena. Due to surface tension forces, the surface layer behaves like a stretched elastic membrane and it tends to decrease its surface area. Unlike an elastic membrane, strictly speaking, the tension in the surface layer is independent of the total surface area of the interface and depends on : i) the nature of the phases in contact and ii) the temperature.

SURFACE TENSION

To increase the surface ΔS, the contact surface between the phases, it is necessary to consume an energy ΔE proportional to this variation of the free surface: $\Delta E = \sigma . \Delta S$

The proportionality factor **(σ) is called the surface tension coefficient.**

For example, at the separation surface of the liquid and its vapors, σ depends on the nature of the liquid and decreases as the temperature increases.

Methods for determining the surface tension:

The stalagmometric method

Methods based on measuring the force required to detach other solids. Modern devices especially use this method.

In the case of a film, the surface tension force of the film is uniformly distributed along the contour of length l and varies directly proportional to its length: $F = \sigma . l \quad \Rightarrow \quad [\sigma]_{SI} = \frac{N}{m}$

Water is the most common solvent in the body.

Water is characterized by a high value of the surface tension coefficient

$\sigma = 72.10^{-3}$ N/m , which is of great importance in many biological processes.

Dissolving certain substances in water can cause changes in its surface tension. The following cases can be distinguished:

If the solute molecules do not change, then the intermolecular forces can hold the hydrogen bond network of the water and the surface tension of the water does not change.

When an electrolyte is dissolved in water, there is a strong interaction between the ions and the dissociation of the electrolyte and the resulting dipoles in water, which increases intermolecular forces and surface tension. This increase is not significant, because shortly after dissolution, the ions are drawn into the interior of the fluid and therefore their concentration in the surface layer decreases.

If substances that have hydrophobic groups in their composition are dissolved in water, they penetrate between water molecules, which reduces intermolecular forces. At the same time, these molecules are expelled on the free surface of the liquid where their concentration increases significantly causing a decrease in the surface tension of the water.

Substances capable of reducing surface tension are called **surfactants – tensioactive agents.**

A typical example is a detergent molecule. Their structures are oriented in solution so that the polar carboxyl groups are directed towards the water molecules and the nonpolar groups towards the fatty acid molecules. This allows the surface tension to be reduced and the impurities to increase their contact surface with the solution, turning into small spherical formations (micelles).

In the human body, the liver secretes substances as surfactants for their functions. Bile, the secretion of the liver is discharged into the duodenum where it facilitates the emulsification of fats. Bile is made up of bile pigments (bilirubin) and bile salts (sodium glycocholate and sodium taurocholate).

The hydrophobic nature of dietary fats makes them structured in the form of droplets, and therefore their circulation and absorption in the intestine is not possible.

But bile salts facilitate their emulsification by orienting their hydrophobic ends toward fat molecules and their polar end toward water molecules. In this way, fat molecules are more easily hydrolyzed into fatty acids and glycerol.

ADSORPTION

Adsorption resides in the accumulation of molecules from a dispersed phase at the surface separating two phases.

It is essential to distinguish between the phenomenon of adsorption and absorption.

- Adsorption occurs at the interface
- Absorption occurs in the solution

Adsorption occurs in two ways.

Chemosorption involves the retension of particles to join at the interface by forming chemical bonds. Adsorption of molecules of a gas on metals (such as CO on palladium catalysts in cars) or adsorption of micromoles on a solid in a solution (such as molecules of stabilizing layers of magnetite particles in a ferrofluid).

The bonds involved in chemisorption are an order of magnitude stronger than for ***physical adsorption*** or van der Waals, electrostatic, or hydrophobic forces. This last category includes the adsorption of macromolecules at interfaces.

Langmuir made a study of the kinetics of the adsorption process at a given temperature as a function of the concentration of the solution near the interface.

Langmuir's model is based on three assumptions:

- Adsorption occurs only in one layer
- All places (positions) are equivalent and the surface is uniform
- The probability that a molecule will adsorb on a given site is independent of the degree of occupancy of neighboring sites.

Under these conditions**, <u>the adsorption process</u> at a given site can be likened to a reversible chemical reaction, characterized by an adsorption rate constant ka, respectively a desorption rate constant kd, which respectively depends on the nature and temperature of the substances involved**.

The rate of change of the fractional coverage, defined as the ratio between the number of occupied adsorption sites and the total number of available sites, is given by:

$$\frac{d\theta}{dt} = k_a.c(1-\theta) - k_d\theta$$

Where: c is the concentration of particles in the dispersed phase in the vicinity of the interface.

ADSORPTION

THE LANGMUIR MODEL

$$\frac{d\theta}{dt} = k_a . c(1-\theta) - k_d \theta$$

The first term corresponds to the direct adsorption process and means that the probability increases with the concentration c, i.e. the fraction of unoccupied sites.

The second term characterizes the desorption process and suggests that the probability increases with the fraction of occupied sites.

At steady state, the fractional coverage becomes independent of time, leading to the cancellation of the left-hand side of the equation and implicitly its right-hand side. The equilibrium value of a θ is:

$$\theta_e = \frac{c}{c+K}$$

$$K = \frac{k_d}{k_a}$$

where **K is the dissociation constant of the adsorbed particles.**

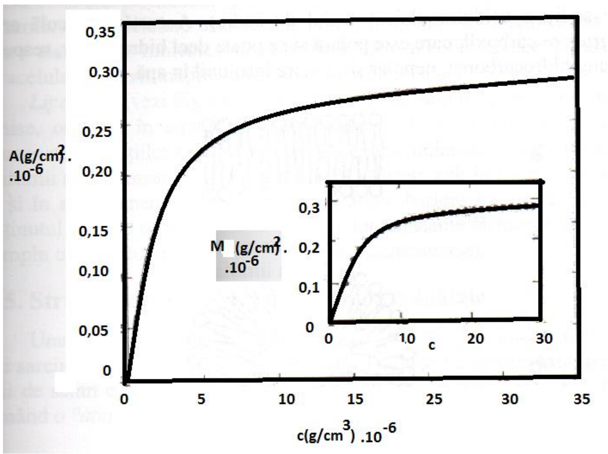
Phenomenologically K is the value of the solute concentration at which half of the adsorption sites are occupied.

Surface recovery can also be catalyzed by the amount of adsorbed substance per unit surface area of the interface and can be expressed in terms of particle number, mole number or mass.

If A is the amount of adsorbed particles per unit area, the partial coverage can be expressed as: θ = A/As

As it corresponds to the saturation value when all available sites are occupied.

The representation of the amount of adsorbed substance as a function of the solute concentration near the interface is known as the **Langmuir isotherm** : $A = A_s \frac{c}{c+K}$



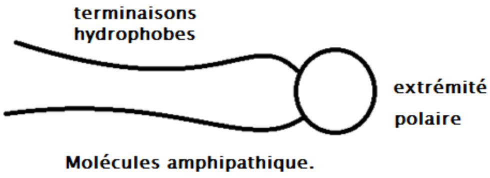
The adjacent table shows the Langmuir isotherms with the parameters:

As = 0.31 μg/cm^2 and K = 2 μg/cm^3

These experimental data correspond to the adsorption of transferrin protein.

the graph →Langmuir's theory provides a correct description of the adsorption phenomena that occur in many systems, including living systems.

ASSOCIATION COLLOIDS



Those molecules that are formed by both hydrophilic polar groups and non-polar hydrophobic groups are called amphipathic molecules.

By dispersing such compounds in water at a concentration above **the critical micellar concentration**, they are organized into small vesicles called micelles.

An example of an amphipathic biomolecule that tends to form micelles is the sodium salt of oleic acid (from sodium oleate). This molecule has a single carboxyl group that is polar and can be easily hydrated, a long-chain hydrocarbon that is non-polar and insoluble in water itself.

Due to this strong hydrophobic chain, sodium oleate has a very low tendency to dissolve in water and form a suitable solution.

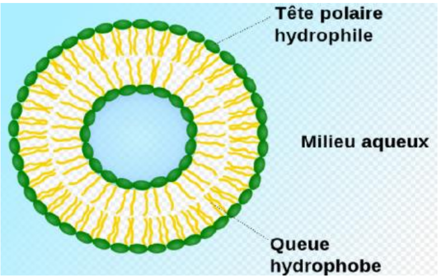
However, they disperse in water to form vesicles in which the carboxyl groups (polar ends) are exposed and form bonds of water molecules, and the non-polar hydrocarbon chains are hidden inside.

AMPHIPATHIC MOLECULES

At the air-water interface, amphipathic compounds form:

- Monolayers with polar ends threaded by water molecules
- Double layers - separates two aqueous compartments

The basic skeleton of cell membranes is the bilayer of phospholipids in which the polar ends of these molecules are oriented towards the aqueous intra- and extracellular environment and the hydrophobic ends towards each other.



Liposomes

LIPOSOMES are vesicular, double-layered structures obtained under certain conditions: exposure to ultrasound of solutions containing amphipathic molecules dissolved in water.

In recent years, liposomes have found wide use in biology, medicine and other fields. They can cross various biological barriers without affecting their content, they are used for pharmacologically active substances for example (carriers for drug molecules).

TRANSPORT PHENOMENA. TRANSPORT OF SUBSTANCE AND HEAT TRANSFER

TRANSPORT OF SUBSTANCE IN SOLUTION

The metabolic processes that take place in living organisms are based on a permanent exchange of substances, energy and information with the environment and between the different internal compartments of the body.

The exchange of substances is carried out due to thermodynamic forces: concentration gradient, potential gradient, pressure, density, increasing entropy, leading the system to thermodynamic equilibrium.

Conserved thermodynamic forces in living systems cause particle flows that are realized in two ways.

DIFFUSION representing the transport of a dissolved substance under the influence of the electrochemical gradient.

OSMOSIS, corresponding to the transport of a solvent under the action of the osmotic pressure gradient.

In living organisms, these two transport phenomena are intertwined; their separate discussion is for educational purposes only.

If in a thermodynamic system there is a non-zero gradient of an intensive parameter, this gives rise to a net transport phenomenon in this system.

DIFFUSION

Dilute solutions resemble gas mixtures.

Solute molecules diffuse, meaning that the liquid solvent spreads throughout the body.

By dissolving a solid in a liquid, the ordered structure is lost and its molecules, hit by the solvent molecules, gain additional kinetic energy.

In turn, the solvent molecules lose some of their kinetic energy, which is expressed in a decrease in the temperature of the solution. To restore the original temperature, heat must be supplied.

By DIFFUSION molecules (or ions) are transported from a higher concentration to a lower concentration.

The spontaneous variation in time of the concentration of the components of a system due to the relative movement of their particles, consists in the transport of a mass or electric charges.

DIFFUSION IN GASES

Gas diffusion consists in the dispersion of molecules of one gas into the molecules of another gas brought into contact with the gas, which leads to a decrease in the mass transport concentration of molecules in each of the gases considered.

According to **FICK'S LAW**, **the mass of gas dM transported by an elementary surface dS is proportional to the surface, given the time interval dt and the direction x of the density gradient that is transported dρ/dx :** $dM = -D\frac{d\rho}{dx}dS.dt$

Where **D is called the diffusion coefficient or diffusivity** and is a constant that depends on the nature of the gas. It is numerically equal to the amount of gas passing through unit area per unit time at a unit gradient and is measured in m^2/s

Based on the molecular kinetic theory of gas we can write:

$$dM = -\frac{1}{3}\bar{v}\,\bar{\lambda}\,m\frac{dn}{dx}dS\,dt \qquad (2)$$

where: dn/dx is the concentration gradient of molecules during diffusion;

$\bar{v}, \bar{\lambda}$ are the mean flow velocity and mean free path of the particles,

Given the relationship: $\frac{d\rho}{dx} = m\frac{dn}{dx}$ (3)

we can write: $dM = -\frac{1}{3}\bar{v}\,\bar{\lambda}\,\frac{d\rho}{dx}dS\,dt$ (4)

By identifying the terms **of the relationship (4) - Fick's law -**

we can write the following expression for **the diffusion coefficient** :

$$D = \frac{1}{3}\bar{v}\,\bar{\lambda}$$

If we take into account the dependence of the average speed and the absolute temperature T and the mean free path of the gas and the pressure p, the following relations are obtained: $D \approx \sqrt{\frac{T}{\mu}}$ and

$D \approx \frac{1}{p}$

Which expresses **the variation of diffusivity** which is proportional to the square root of the temperature and inversely proportional to the square root of the molecular mass μ and the pressure of the gas p.

LIQUID DIFFUSION

The diffusion of fluids takes place by the transport of molecules of foreign substances (liquids or gases) in liquid concentrates in order to reduce them.
On a microscopic scale, diffusion in liquids presents characteristics much more difficult to treat theoretically than for gas or solids.
Macroscopic phenomena obey Fick's law.

DIFFUSION IN SOLIDS

Diffusion in solids consists in the dispersion of atoms or molecules of a solid body in another solid brought into contact.
The phenomenon can be studied on an atomic scale (microdiffusion)
or the macroscopic scale (macrodiffusion).
In the case of the diffusion of solid impurities in crystals for the study of microdiffusion, the individual acts of displacement of the impurity atoms in the fundamental networks are taken into account.
We know several mechanisms of the movement of atoms:
between the nodes of the crystal lattice, impurity atoms with a size smaller than that of the lattice atoms. From an energetic point of view, the individual act of passing impurity atoms from one internode to another neighbor, consists in overcoming a potential barrier value Wm.

The scaling frequency of this potential barrier is calculated using the equation: $f = z\nu\, e^{-\frac{W_m}{kT}}$
Where :

ν is the number of collisions per second on the barrier walls
z is the number of nodes through which the atom can pass
k is the Boltzmann constant
T is the temperature of the solid body

In the vaccum of the crystal lattice, the impurity atoms have dimensions comparable to those of the lattice.

The frequency of the escalation of the potential barrier, which occurs in the individual act of moving from a node to a vacant place, is given by the relation analogous to the previous one: $f = z\nu\, e^{-\frac{W_m + W_\nu}{kT}}$ where Wν is the energy required to cross the potential barrier formed upon vacancy generation.

Exchange between impurity atoms of occupied sites at lattice nodes.

The frequency of individual broadcasting acts is used to calculate **the diffusion coefficient** and establishing its dependence on temperature.

$$D = D_0 e^{-\frac{Q}{kT}}$$

Where:

D_0 is the common factor that depends on the microscopic diffusion mechanism and

Q is the activation energy of the mechanism (which is equivalent to the energy barrier height Wm or Wm + Wν)

AMBIPOLAR DIFFUSION

Ambipolar scattering of charged particles occurs when their mean free path is smaller than the dimensions of space, where there is also a difference in the concentration of particles with both signs (positive and negative) in a given direction.

It is a positive column of a luminescent discharge in a tube with insulating walls.

Electrons with higher mobility negatively charge the insulating wall.

This negative charge helps to accelerate the positive ions towards the wall and at the same time electronically brake them to achieve a steady state when the travel velocities of the two types of carriers become equal.

During the collision with the wall, the electrons recombine with the ions in the plasma layer in its immediate vicinity, which leads to the establishment of a concentration gradient of both ions and electrons directed towards the wall.

This phenomenon depends on the nature of the gas and in general the number of particles decreases when the pressure increases.

DIFFUSION – FICK'S LAW

From a macroscopic point of view, **the number of impurity atoms transported per unit time through a certain surface S is given by FICK'S LAW :** $\frac{dN}{dt} = -D\frac{dC}{dx}S$

Where :

dN/dt is the number of atoms transported per unit time

D is the diffusion coefficient,

dC/dx is the concentration gradient in the x direction.

The relationship shows that mass transport is the goal of decreasing the concentration of impurity atoms.

Fick's first law : $\frac{1}{S}\frac{dN}{dt} = -D\frac{dC}{dx}$

Fick's second law : $\frac{dC}{dt} = D\frac{d^2C}{dx^2}$

$$[D]_{C.G.S} = \frac{cm^2}{s}$$

Diffusion coefficient

- for micromolecules: M < 10^3 Da ; D ~ 10^{-5} cm^2/s

  $$D = \frac{8.10^{-5}}{\sqrt{M}}$$

- for macromolecules: 10^3 Da < M < 10^8 Da ; D ~ 10^{-8} cm^2/s

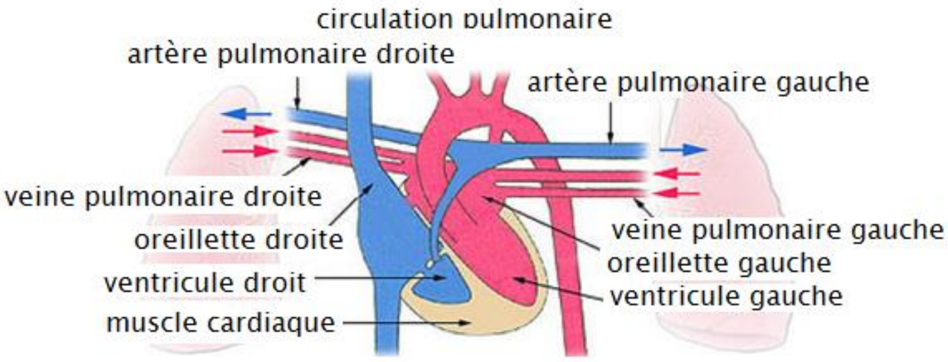
  $$D = \frac{3,2.10^{-5}}{\sqrt{M}}$$

- for spherical particles: the Stokes-Einstein relation: $D = \frac{k.T}{6.\pi.\eta.r}$
- 1 Da = 1.660 538 86 (28)×10^{-27} kgN) = Unit of measurement for mass

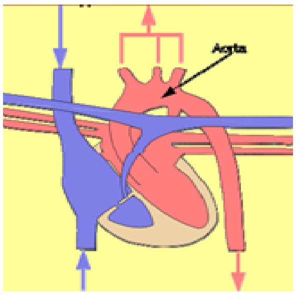
APPLICATION OF DIFFUSION IN THE HUMAN BODY

Diffusion of CO_2 from tissues to plasma is realized according to the following equation:

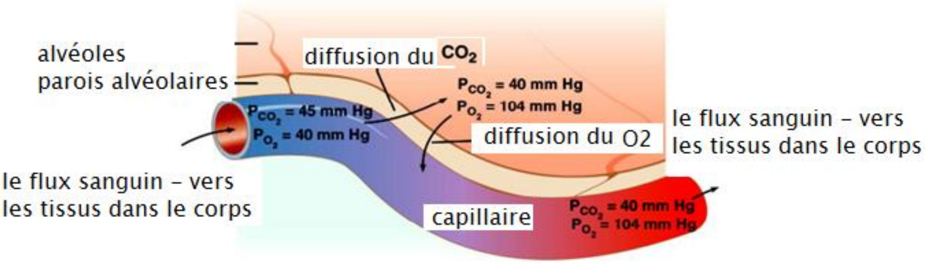
$$CO_2 + H_2O \xrightarrow{\text{anhydrasecarbonique}} H_2CO_3 + H^+ + HCO_3^-$$



circulation pulmonaire
le sang désoxygéné entre dans le cœur par l'artère pulmonaire du ventricule droit jusqu'aux poumons
le sang oxygéné par les poumons atteindre le cœur de l'oreillette gauche à travers les veines pulmonaires.



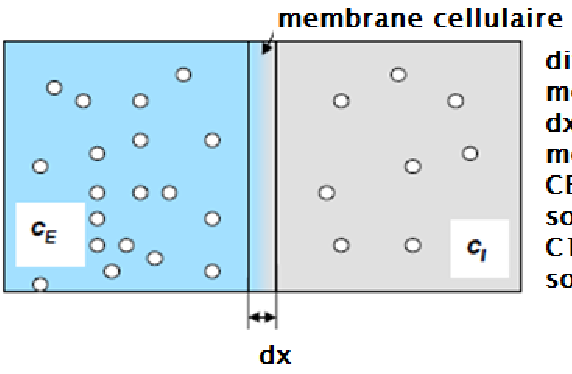
circulation systémique
le sang oxygéné
pénètre dans le ventricule gauche du coeur à travers l'aorte et atteint les tissus.
le sang désoxygéné
de tissus atteindre le coeur dans l'oreillette droite par la veine cave.



2% de l'oxygène est transporté à travers le plasma
98% de l'oxygène est transporté à l'aide du composé Hb (O2) 4

Diffusion of CO_2 tissue from plasma:

CO_2 - carbon dioxide is transported as follows:



diffusion simple à travers la membrane cellulaire
dx – l'épaisseur de la membrane cellulaire
CE – concentration de la solution
C1 – concentration de la solution intracellulaire

- 7% dissolves in plasma
- 23% as $HbCO_2$ complex
- 70% as HCO_3 ions

The diffusion of gases is manifested in the phenomenon of respiration in the exchange of gases in cells.

Gas exchange with the external environment takes place in three phases:

- **the first phase** of external breathing, the exchange of respiratory gases takes place between the body and the external environment through appropriate structures

- the second phase is represented by the internal environment for gas transport and gas exchange between cells and the internal environment.

- the third phase of intracellular respiration, which makes it possible to obtain energy in the cells through the catabolic degradation of organic substances.

SIMPLE DIFFUSION THROUGH THE CELL MEMBRANE

Consider a permeable membrane separating two media of different concentrations.

Consider that the exchange membrane flows under steady conditions.

According to **Fick's first law** we obtain:

$$J = \frac{\Delta m}{S.\Delta t} = -D\frac{c_1 - c_E}{\Delta x} = D\frac{c_E - c_1}{\Delta x} = \frac{D}{\Delta x}\left(c_E - c_1\right) = P\left(c_E - c_1\right) = P\Delta c$$

where P is the permeability coefficient of the membrane

OSMOSIS

Osmosis is the phenomenon of solvent molecules passing through a semi-permeable membrane from a dilute solution to a more concentrated solution.

The phenomenon of osmosis can be demonstrated with the Dutrochet osmometer.

Consider a container containing pure solvent (water) into which a funnel is passed upside down, covered with a semi-permeable membrane (permeable only to solvent molecules and not to solutes). The funnel contains a substance in the same solvent (eg glucose or sucrose solution).

The appearance, after a certain time, of differences in level between the liquid in the container and the funnel is observed. Since the solute molecules are too large to cross the membrane pores, the difference in level is obviously explained by the passage of solvent molecules from the container containing the pure solvent into the funnel containing the solution.

The level of the liquid in the funnel will pass to the equilibrium state, characterized by an equality of the values of the hydrostatic pressure exerted by the column of liquid in the tubular part of the funnel and the pressure that pushed water from the container into the funnel, called osmotic pressure.

The equilibrium condition is written

$$\pi = \rho . g h \qquad (1)$$

Where :

π - is the osmotic pressure;

ρ - is the density of the solution;

h - is the height difference between the liquid in the container and the funnel

g - acceleration of the gravitational field

Osmotic pressure is the pressure necessary to stop the osmosis phenomenon.

Note: Dilute solutions behave similarly to ideal gases.

The osmotic pressure formula can be written by analogy with the thermal equation of state of ideal gases: $pV = \nu . RT$ (2)

If equation (2) is divided by the volume V we obtain: $\pi = cRT$ (3)

Which is named the Van't Hoff's law:

where, in equation (2)

p - gas pressure
V - volume of gas
ν – amount of substance (number of moles)
R - ideal gas constant
T - absolute temperature

And in equation (3)

c- the molar concentration of the solution in the solution;

π - osmotic pressure

Van't Hoff's law can be extended to electrolyte solutions.

However, for electrolyte solutions, the osmotic pressure is higher than that obtained with equation (3).

This is because the osmotic pressure is determined by the number of particles that cannot cross the semi-permeable membrane called osmotic active particles and does not depend on the nature or mass of the solutes.

To write a general formula for calculating osmotic pressure, it is necessary to introduce a new type of concentration called OSMOLAR CONCENTRATION, which takes into account the dissociation of dissolved substances in the solution and which is given by:

$$c_{os} = \Sigma n_i . c_i \qquad (4)$$

where n_i - is the number of particles (ions) resulting from the dissociation of a molecule of the substance,

and c_i - is the molar concentration of this substance

Van't Hoff's law can also be extended to electrolytic solutions:

So:

- For strong electrolytes: the calculation of the osmolar concentration will use the equation: $c_{os} = \Sigma n_i . c_i$

with n >1

- For weak electrolytes, since they dissociate easily, we use the approximation: $\pi = cRT$ with $n_i \approx 1$
- For non-electrolytes, which do not dissociate at all in solution, $n_i = 1$

Thus, in the Van't Hoff relation: $\pi = c_{os} \cdot R \cdot T$ a replacement of the molar concentration *c* with the osmolar concentration c_{os} is required.

So we can write: $\pi = c_{os} \cdot R \cdot T$

By putting two solutions in contact with different osmolarity concentrations c_{os1} and c_{os2}, a difference in osmotic pressure will take place :

$$\Delta\pi = \pi1\text{-}2\ \pi = RT(c_{os1} - c_{os2}) \qquad (5)$$

$$\text{Or } d\pi = RTdc_{os} \qquad (5')$$

Which will push the solvent from the more dilute solution to the more concentrated solution.

When changing the solvent through a semipermeable membrane that separates two solutions of different osmolar concentrations, a mechanical work called osmotic work is performed:

$W= \nu.RT\ln(c_{os1} /c_{os2})$ (6)

METHODS OF DETERMINING OSMOTIC PRESSURE

DIRECT METHOD

Direct methods are based on measuring osmotic pressure, defining osmotic pressure and using the Dutrochet osmometer (osmotic cell).

This will determine the amount of osmotic pressure by measuring the hydrostatic pressure that balances it (being equal to the difference in height of the liquid in the dish and the funnel).

The method is used less and is only suitable for small values of osmotic pressure.

INDIRECT METHOD

EBULIOSCOPIC method: In this case, the boiling point of a liquid under normal conditions is the temperature at which the pressure of the vapors saturated with the liquid becomes equal to the atmospheric pressure during which the evaporation takes place (H = pm = 1 atm).

Dissolving substances in liquids has the effect of lowering its saturation vapor pressure, so that the solution must be heated to a higher temperature for the new value to match the ambient pressure.

EBULIOSCOPIC effect: is to increase the boiling point of a solution compared to the pure solvent: $\Delta t_{eb} = t_{b\ solution} - t_{b\ pure\ solvent}$

In the case of dilute solutions, the increase in the boiling temperature Δt_{eb} is proportional to the osmolar concentration of the solution:

$\Delta t_{eb} = k_{eb} .c$ - Raoult's law

Where k_{eb} depends only on the nature of the solvent. Its values are totaled.

For example for water: $k_{eb} = 0.52$ °C / M

Knowing the value of the ebullioscopic constant and determining Δt_{eb} makes it possible to find the osmotic pressure of the solution: $\pi = RT(\Delta t_{eb} /k_{eb})$

CRYOSCOPIC METHOD

THE CRYOSCOPIC EFFECT or freezing is the lowering of the freezing point of a solution compared to the pure solvent.

Δt_{cr} = ttpuresolvent - ttsolution

where tt is the freezing (or melting) temperature.

The lowering of the freezing point of the solution relative to the pure solvent is proportional to the osmolarity concentration of the solution.

$\Delta t_{cr} = k_{cr}.c$ Raoult's law

When the proportionality constant depends on the nature of the solvent:

Water: k_{cr} = 1.86°C/M

For blood plasma: k_{cr} = 0.56°C/M

Dividing the relation $\Delta t_{cr} = k_{cr}.c$ by the relation π = cos. RT

We obtain: $\pi = \Delta t_{cr}. [(RT)/k_{cr}]$

OSMOTIC PRESSURE

The increase in boiling temperature, respectively lowering the freezing point of a solution relative to the pure solvent leads to a number of practical applications.

One such example *is the antifreeze (ethylene glycol* $(CH_2OH)_2$*)* , characterized by a very low freezing temperature used in car radiators during the winter.

Osmotic pressure of blood plasma

Blood plasma is an **aqueous solution** having the composition:

- Ions (i): Na^+, K^+, Cl^-, Ca^{2+}, etc.
- Undissociated molecules (mn) urea, glucose, amino acids, etc.
- Protein macromolecules (p): albumin and globulin

The osmotic pressure is the sum of the osmotic pressures generated by these components $\pi = \Sigma\pi i + \Sigma\pi mn + \Sigma\pi p$

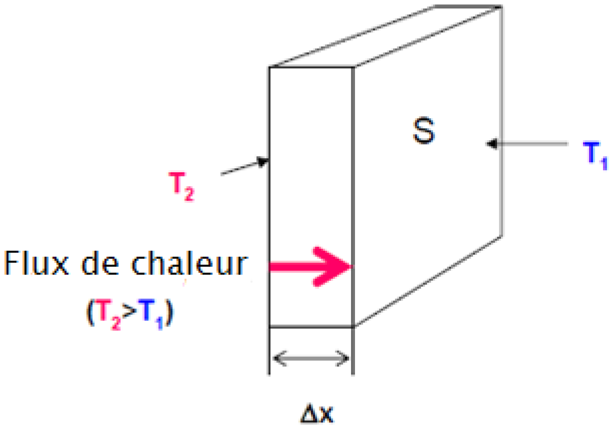
π plasma = $R \cdot T \cdot c_{os\ plasma}$

$c_{os\ plasma}$ = 0.303 osM

π plasma = 25.4. 0.303= 7.6 atm

HEAT TRANSFER THROUGH CONDUCTION, CONVECTION AND RADIATION

HEAT TRANSFER THROUGH CONDUCTION



Heat transport through a conducting material of surface area S and thickness Δx

The heat flux J_o is the amount of heat ΔQ that passes through a unit area S in a unit time ΔT

$$J_o = \frac{\Delta Q}{S.\Delta T}$$

Heat flow and temperature gradient depend on the nature of the substance - **Fourier's law**

$$J_o = \frac{\Delta Q}{S.\Delta T} = -\lambda \frac{\Delta T}{\Delta x}$$

The amount of heat transported per unit time depends on the cross-sectional area through which heat transport occurs, the temperature gradient and the nature of the substance

$$q = \frac{\Delta Q}{\Delta T} = -\lambda.S.\frac{\Delta T}{\Delta x}$$

$$R = \frac{\Delta x}{\lambda.S}$$

$$q = \frac{\Delta Q}{.\Delta T} = -\frac{\Delta T}{R}$$

Where :

λ is the coefficient of thermal conductivity

R is the thermal resistance of the medium

COMMENTS:

- Thermal conduction in the case of metals is obtained mainly through conduction electrons
- In the case of non-metals, it is done by sound conduction
- The conductivity of the crystals depends on the direction because they are anisotropic systems
- The thermal conductivity of liquids is lower than that of solids, and that of gases is lower than that of liquids
- Thermal and electrical conductivity increases when the temperature decreases.

HEAT TRANSFER THROUGH CONVECTION

Convective heat transfer takes place by means of a fluid (liquid or gas) that comes into contact with a compact solid material having a different temperature.

Heat exchange through the process of convection occurs more slowly than in the process of conduction. For example: room heating in winter is done in most cases by convection. Although it is an insulator, air can easily carry heat through the currents that form in a room where there is a heat source - for example a radiator.

If the body in contact with the air mass is at a lower temperature, then the hot air can give up some of its energy and cool down. Air becomes denser by cooling, it will "fall" and will be replaced by a quantity of warm air inside. In this way, a continuous flow of air is created around the wall of the room and at the same time a transfer of heat from the warm air to the cold wall.

By heating the contact point with a hot source, the density of the fluid changes and causes updrafts to form.

The law of heat propagation by convection is given by the following formula:

Newton's law: $q = hST$

$[h]_{SI} = 1\ W/m^2.K$

where h - is the convection coefficient
S is the area of the contact surface
ΔT is the temperature difference between the contact surface and the surrounding medium.

HEAT TRANSFER THROUGH RADIATION

Unlike conduction and convection, radiant heat transport is not necessary for energy transport. Thermal energy is transmitted by electromagnetic waves with wavelengths longer than that of red light in the visible spectrum with $\lambda > \lambda_{red}$ carrying heat. They are called INFRARED RADIATION.

- DIATHERMANE - are the organisms that allow the passage of infrared radiation and
- ATHERMANE are organisms that do not allow the passage of infrared radiation

When a metal body reaches the temperature of 500°C, it becomes red and bright. By further increasing the temperature variation, the color becomes white.

The heat that the body receives by heating is transformed into radiant energy

Radiant energy emitted per unit time is called the emitter power of the body (radiant power)

A body that absorbs all the radiation that falls on it is called a BLACK BODY.

When a blackbody is heated, it emits all the radiation it can.

The blackbody is defined as a perfect emitter and also a perfect absorber of radiation.

The radiation power of the blackbody is given by:

$$q = \frac{\Delta Q}{.\Delta T} = \sigma .S.T^4$$

$$\sigma = 5{,}669.10^{-8}\ \frac{W}{m^2K^2}$$

Stefan-Boltzmann law

(σ = Constant Stefan - Boltzmann)

For a real body, the radiant power is expressed as: $q = e.\sigma .S.T^4$

Where :

e is the emissivity of the body

e = 1 for a black body

e = 0.97 for the human body

e = 0.02 for polished aluminum surfaces

HEAT TRANSPORT THROUGH THE BODY

The human body produces heat which is transmitted from the center of the body to the surface and therefore to the external environment.

The amount of heat and body temperature varies from organism to organism.

Heat is transported from places of higher temperature to places of lower temperature by conduction and convection.

The thermal conductivity of the tissue is reduced, especially in thick ones, so that the main role in the transport of heat belongs to the blood.

Heat transfer through blood is also favored by its high specific heat, approximately equal to that of water (1cal/g.degree or 4185J/kcal.degree)

The transport of heat from the interior of the body having temperature T1 to the surface of the body having temperature Ts is given by:

$$Q1 = C1\ (T1-Ts)$$

where C1 is the thermal capacity of the body to transfer heat from the inside to the surface.

The heat transport from the surface temperature Ts of the body to the external environment at the temperature Te is given by:

$$Q2 = C2\ (T-To)$$

where C2 is the heat capacity of the body to transport heat from its surface to the environment.

In a stationary state Q1 = Q2, namely: $\frac{C_1}{C_2} = \frac{T_S - T_e}{T_i - T_s}$

C1 (T1-Ts) = C2 (T2-Ts)

C1 / C2 = thermal circulation index

Heat transfer to the outside is achieved by conduction, convection, radiation and evaporation of water through transpiration.

Heat transfer to the outside by conduction, convection, radiation is about 70-80% of the total heat transfer to the outside, and by evaporation 20-30%.

In case of physical exertion, heat loss through evaporation is 60-70% of the heat.

In the case of intense physical work, the body can lose 4-12 liters of water through evaporation, which represents a significant release of heat.

If the layer of air on the skin is about 4-8 mm, called the marginal layer, the body will resist heat removal by conduction and convection currents.

The thickness of this layer decreases when the body is in motion.

PHYSICAL AND CHEMICAL PROPERTIES OF THE CELL, NUCLEUS AND BIOLOGICAL MEMBRANES

CELL

Physical parameters

The cell is the morphofunctional unit of the living matter, the smallest unit capable of independent life.

The parts of the cell are as follows:

1. CELL MEMBRANE: separated from the extracellular environment, which should be considered an organ and not a passive film, as it is the seat of biophysical and biochemical activities related to complex transport processes.

2. NUCLEUS is the main office of genetic information. The place where it takes place the protein synthesis

3. CYTOPLASM (intracellular fluid) is intermediate between the consistency of soil and gel and a heterogeneous structure due to the organelles inside. A network of filaments crossing the cytoplasm was highlighted, such as the cytoskeleton or the microtrabecular network with an important role in cellular metabolism.

4. ORGANELLES OR MITOCHONDRIA, endoplasmic reticulum, Golgi apparatus, liposomes, etc. , perform specific functions.
The shape of the cells is varied: spherical, cylindrical, oval, with stable or variable geometry.
The nerve cell has a long pole called an axon and one or more short extensions called dendrites.

	name	**numbers**	**diameter**
1	erythrocytes	25000.10^9	7÷8 µm
2	the neurons	86.10^9 -in the brain 17.10^9 - in the cortex $69.\ 10^9$ - in the cerebellum	3÷100 µm
3	glial cells	84.10^9 -in the brain 68.10^9 - in the cortex 16.10^9 - in the cerebellum	
4	hepatocytes	100.10^9	
5	lymphocytes		6÷8 µm
6	adipocytes		60÷120 µm

CELL - PHYSICAL PARAMETERS

TYPES OF CELLS. PHYSICAL FORM

A **NEURON**, or **NERVE CELL, is an excitable cell that is the basic functional unit of the nervous system.** The term "neuron" was introduced into the medical vocabulary in 1881 by the German anatomist Heinrich Wilhelm Waldeyer.

Neurons transmit a bioelectrical signal called a nerve impulse.

The total number of neurons in the human brain is estimated at 86 to 100 billion (10^{11}). The brain is not the only organ that has a high concentration of neurons: the gut, for example, accounts for up to 200 million.

Neurons would be about as numerous as glial cells, secondary components of nervous tissue providing several functions including the support and nutrition of neurons.

PHYSICAL STATE OF THE CELL

The knowledge we have about the physical state of the cell, about biophysical processes, as well as many other biological processes, shows a duality: clear questions with ignored problems.

The explanation is that throughout the development of science there are conflicting theories about a physical term encountered in biology, even if the significant phenomenon of the inanimate world is well explained.

On the other hand, the complexity of living matter, as well as its fragility, explains why we have no definitive conclusions about certain apparently simple biophysical quantities, such as the viscosity of protoplasm, its elasticity, etc.

We can say that, in general, the problems of biophysics, but so widely studied and discussed, are still open.

Since the multicellular living organism cannot be considered as a sum or colony of cells, neither do the biological, cellular processes result from the simple sum of the physical and chemical processes of the cell.

Cytology is undoubtedly the basis of understanding the phenomena of life, and cytophysiology has, not only as an integral part, but also as fundamentals, cellular biophysics and biochemistry. The major methodological difficulties come from the smallness of the object and the need to study it under conditions close to natural and functional ones.

MOLECULAR CONCENTRATION

The molecular concentration in cells is different from plants and animals, it differs from one group of living organisms to another.

Plants in which osmosis covers a very large scale and participates in numerous adaptations, are characterized by a large variability of osmotic pressure , 1-200 atm (PJKramer, 1955).

Such a high molecular concentration partly explains the frost resistance of plants.

In domestic animals the osmotic pressure varies within much closer limits.

In humans, for example, it is 6-7 atm, corresponding to a freezing point

$\Delta t = - 0.56$ °C lower than marine animals and selachians $\Delta t = - 2C$ °.

Osmotic pressure in higher animals is filled by minerals and electrolytes, while in selachians mainly by organic substances (urea and trimethylamine oxide).

In the cells of the organs of evolved animals the molecular concentration is slightly higher than that of the internal environment.

PROTOPLASM CONTAINS:

- Mineral solids dissolved in the form of molecules and ions (K^+ , Na^+ , Ca^{2+} etc.) in the intracellular liquid

- Ions and gaseous molecules (O_2 , N_2 , H^+ , O^{2-} , etc.)

- Inorganic ions (especially K^+ , Na^+ and Ca^{2+}) involved in the processes of colloid balance, in permeability to excitation, in the development and control of metabolism .

Liquids are aqueous solutions. The amount of water in living bodies in a state of activity that can reach 95% of the body mass (eg jellyfish).

The cell contains a large number of characteristic organic substances: protein substances, fats, carbohydrates, etc. The proportion in which these substances are found varies from one type of cell to another, depending on the nature of the cell species (plant or animal), organ, age and function.

Cellulose characterizes plants.

Collagen characterizes higher animal organisms.

Chlorophyll is found only in green plants.

Plant cells generally contain more water than animal cells (some algae contain up to 98% water).

Lifetime is a decisive parameter for the stability of radiosensitivity and radioresistance of cells.

It is of particular importance for understanding the mechanism of interaction of ionizing radiation with living matter.

pH:

The pH of the cell depends on the type of cell.

Average pH value of 6.9.

This value is the same for all cells.

Nucleus pH = 4-5 - more acidic

Gastric juice pH = 1-2.

Possible intracellular pH changes that occurred when substances enter the cell are prevented by the buffers in said cells.

The intracellular pH is a slightly acidic environment

Viscosity varies with cell age and temperature

	Name	**lifetime**
1	erythrocytes	100-120 days
2	the neurons	
3	glial cells	
4	hepatocytes	
5	lymphocytes	months-weeks
6	adipocytes	
7	Platelets	5-9 days
8	mitochondria	21 days

VISCOSITY OF PROTOPLASM

A more controversial question is whether or not protoplasm is a Newtonian liquid, whether Newton's law also holds for it.

The viscosity of several lyophilic colloids does not obey Newton's law.

When the flow rate is low, the viscosity coefficient does not depend on the velocity gradient and the flow rate depends on the applied force.

Peiffer showed that the cytoplasm is presented as a Newtonian fluid. However, according to LV Heilbron (1958), many varieties of protoplasm can be considered Newtonian fluids because the observed deviations are negligible.

Determination of viscosity is done by several methods.

From the variety of these processes we can draw two groups.

- One of them is based on Stokes' law of the fall or motion of small spheres in a viscous liquid.

- The other group is based on Einstein's law regarding the connection between the Brownian motion of suspended particles and the average viscous suspension.

Biophysical experimentation is often used in place of the centrifugal force of gravity. Observations are made using a centrifugal microscope.

Arbaccia sea urchin eggs withstand centrifugation for several minutes at accelerated centrifugation ($g = 9.81\ m/s^2$). But many small-celled organisms do not withstand centrifugation, they were destroyed before the viscosity could be determined. They resist the actions of static magnetic fields.

So, for the determination η, some authors such as Heilbroun L. in 1922, used the study of the circulation of spherical grains of iron or nickel, under the action of a magnetic field determined both in the cytoplasm and the viscosity of the liquid, which is also known.

It should be noted that the numerical values are obtained approximate average values of the coefficient of viscosity η, since the density of the protoplasm varies from one point to another, and intense weathering of the cell decreases the value of this coefficient.

The viscosity of the cytoplasm varies during cell division.

It is maximal in anaphase and telophase (after W. Fry, 1934), both for plant and animal cells (LV Heilbrun, R. Chambers, etc.).

Protoplasm is an aqueous solution in which ions and small molecules are dissolved : glucose, C_2 , N_2 , CO_2), proteins of macromolecules and nucleic acids (either according to the size of colloidal solutions) and in the cells organelles that are suspended from various polyribosome granules.

In terms of the concentration of dissolved particles in plants and bacteria, hence osmolarity, this can vary greatly between 1 and 200 atm (0.015 to 10 M). High concentrations correspond to dormant forms (causing frost resistance, dryness and spores).

In animals the osmotic pressure varies little in the internal environment – in humans the osmotic pressure is about 7 atm, the freezing depression is $\Delta T = 0.56\ ^oC$.

The concentration is approx. 0.3 M, there are various mechanisms that maintain a constant total osmolar concentration that is quite accurate.

As a type of solution, the cytoplasm lies between the very loose ground state and the gel state composed of ribbon molecules and membranes of the endoplasmic reticulum in which there is a fibrillar ground net.

NUCLEUS

The nucleus contains a nuclear sap (karyolyph) surrounded by a nuclear membrane, which forms the bulk of the nuclear mass.

To the liquid nature of the nuclear content, the following facts can be stated:

- the core is deformable and elastic (like an inflated rubber balloon);
- its shape at rest is spherical;
- to perforate the membrane, the nucleus removes a droplet or may mix the contents of the cytoplasm;
- nuclear inclusions are spherical;
- brownian motion (sometimes more active than in the cytoplasm) and currents (up to 2 μm/min) are observed;
- nuclei may fuse when contact fusion is favored by favored drugs and alkaloids.

The viscosity evaluations gave different values depending on whether the determinations were based on Stokes' law or Einstein's law.

For nuclear juice, values of 0.02 to 0.07 poise have been proposed ; probably because viscosity varies from cell to cell and is variable with time (relative to functional state, etc.) and various physical and chemical factors.

The nuclear colloidal system has been characterized as a "labile polyphasic system of hydrosols" (Lepeskin) as well as a "ground-state coacervation complex" (Peterfi and Kojium, 1936).

It has not only an emulsion and dispersoid (micron particles, which are visible under an optical microscope).

The nuclear soil structure appears to be unstable.

Periodic mechanical shocks can lead to coagulation of the core, the appearance and disappearance of structures (as in the phenomenon of thixotropy). Mechanical shocks can act as an indirect exciter. Acidification leads to reversible freezing and alkalinization to core liquefaction.

The nucleus is shown entirely as a viscous liquid in which the nucleoli can move. Heilbrun calculated the viscosity of the echinoderm egg, determining from Stokes's law the rate at which the nucleoli fall into the intranuclear fluids. The value found for liquid is 0.002 $N*s/m^2$ (i.e. twice that of water), thus equal to the vacuole viscosity of the cytoplasmic contents.

The nucleus is an **"open system"** that exchanges substances with the cytoplasm: from a microscopic and biochemical point of view, the image of substances or particles and their secretion and excretion have been demonstrated.

It is an **autonomous osmotic system** from the point of view of environmental tonicity variables, it presents phenomena of turgescence (soil state), imbibition (gel state), vacuolization, shriveling, etc.

As for the pH of the karyolymph, it is lower in the plant cell nucleus than in animals, i.e. 4.2 to 5.8 (Yamaha and Ishii, 1939) and from 6.4 to 7 plants 5 (Reiss , 1924) in animals. In an infusoria macronucleus (DN Nasonov, 1932) the intranuclear reaction depends on a phase of the mitotic cycle.

R. Chambers states that the nuclei of plant cells are more viscous than the cytoplasm.

According to Serra, A. (1955), **the viscosity of the nucleus (plant) is 9-19 times that of water (in the cytoplasm, while the viscosity is 1.2-30 times that of water).**

Spyrogyra nuclei have a density of 1.090 g/cm^3, while the density of the cytoplasm is only 1.076 g/cm^3.

According to Heilbrun's research (1955), the karyolymph density is 1.04 g/cm^3 and the nucleoli 1.14 g/cm^3.

In ultracentrifugation, the basic components are subjected in the following order: nucleolus, chromosomes, cytoplasm, nuclear juice.

The surface of the core is sticky; the nucleus can capture mitochondria, plastids, bacteria, Golgi elements.

Adsorption plays an important role in vital staining of nuclei.

Surface tension determines a number of core properties; surfactants, such as octanol (which lowers the surface tension of water by 32-36 dynes/cm), cause significant degenerative changes in the nucleus.

The essential characteristic movements in some cells (having the character of tactics to chemical, traumatic, light influences, etc.) could be explained by influencing the production of surfactants and viscosity.

The cell nucleus has cellular elastic properties, changes in its shape are reversible. During centrifugation of Chera, Euglena cells, the cytoplasm twists and the nucleus bends at right angles to the fold without breaking.

The experiments of Milovidov PF (1949) on plant cells demonstrate that the nucleus is deformed not only by pressure, but also by tension (by means of metal needles inserted into them); the deformation is elastic as long as the cell lives.

E. D'Angelo (1946) can elongate chromosomes within the nucleus to about five times their original length. If the nucleus is removed from the chromosomes, they can be stretched up to 25 times their normal length. This result can be explained, in part, by the relaxation of the helical structure of the chromosomes.

The optical qualities of the core are evaluated in different ways.

After Pfeiffer (1936) Refractive index is slightly higher ($n = 1.40$ to 1.42) than that of cytoplasm ($n = 1.38$ to 1.40), but varies greatly with humidity, pH, ion concentration, pressure.

The maximum refraction (at a $n = 1.50$) have chromosomes.

On ultramicroscopic examination against a black background, the nucleus sometimes appears indivisible (which means that most are microscopic colloidal particles, ie less than 4 mm in diameter) sometimes granular.

If the cell is in distress, the nucleus appears milky.

In polarized light it has birefringence (Brandt, 1885), which is negative due to DNA (WI Schmidt, 1944). Proteins show positive birefringence, as do lipids; chromosomes may change the sign of birefringence during mitosis (or cytological manipulation), probably due to quantitative changes in chemical composition. What matters, however, is the ultrastructure. Birefringence is obtained and also the paracrystalline nucleoprotein structure (Rinne, 1930) and depends on the "spiral" chromosomes.

In the selective absorption of electromagnetic waves, the nucleus absorbs intensely in the X spectrum (due to its content of Ca, Fe, P), the ultraviolet spectrum (due to the content of DNA) and infrared. The nucleoli of some cells become luminescent in ultraviolet.

The electrical characteristics of the nuclei depend on the pH.

According to Guilliermond A. and A. Choucroun (1936), the nucleus is negatively charged (especially the "chromatic substance" of the nucleus). According to Gelfan (1931) the interior of the nucleus of the Asteria egg is positively charged (at a potential difference of 10 mV) Research by Bruchtal and Peterfi (1937) shows that the potential difference between the nucleus of Amoeba and the cytoplasm is twice that of of the cytoplasm and the external environment.

The isoelectric point of the nuclei of adult tissues is at a pH of 3.0 to 4.2 lower than that of the cytoplasm which is 4.0 to 6.5. The importance of the isoelectric point is multiple (PF Milovidov, 1949). At this point, there are minimal electrical charges in the system, minimal viscosity, imbibition, pressure, and osmotic stability. There is also a maximum sensitivity to external factors that cause flocculation and coagulation. In electrophoresis, the nucleus and nucleolus advance toward the anode; These organisms do not migrate in electrostatic fields (W. Beier, 1950).

- The position of the central frequency of the cell nucleus was explained by the action of electrical (Gh. Gerassimoff 1899) or mechanical (Nemea) forces. Guilliermond and A.

Choucroun discovered, however, that the components of living cells do not move from their original position or under the influence of intense electric fields (50 V/cm).

- WR Locwenstein, I. Kanno, M. Ho (1933) studied the permeability of the nuclear membrane in the salivary glands of insects. The membrane constitutes, in this case, a barrier of 1 to 10 Ω/ cm^2 to ion diffusion, separating two phases with relatively low resistivity (100 Ωcm) and unequal potential (2-15mV). The barrier has a strong reactive capacitive component and, unlike plastic membranes, many excitable elements do not have many rectifying (rectifier) properties and are not depolarized.
- Electromicroscopic examination shows pores of size 0.05 μm, located at intervals of 0.10 μm. If free communication between nucleoplasm and cytoplasm was established through these pores, the resistivity should be only 10^{-3} Ωcm.

CELL MEMBRANE

COMPONENTS OF THE CELL MEMBRANE

The cell membrane is the boundary between the intra and extracellular environment.

The main functions of the cell membrane are:

1. **It carries out the compartmentalization of living matter**, forming a barrier that separates the intracellular and extracellular compartments after them.
2. **It is the place of the transport process**

Transport of substances across the intact membrane through pores or ion channels (water, ions and molecules)

Information transfer through conformational changes of membrane components (nerve transmission along excitable cells)

Transport of macroproducts by membrane rupture followed by its recovery (pinocytosis)

3. **It is the seat of membrane receptors** (receptors for hormones, chemical mediators)
4. **Provides mechanical strength to the cell that is separated from the extracellular environment**
5. **It is the place of electrical phenomena** (bioelectrogenesis, nerve transmission)

CELL MEMBRANE STRUCTURE:
MEMBRANE LIPIDS

The cell membrane includes a wide variety of lipids, their main role is to form matrix retention proteins.

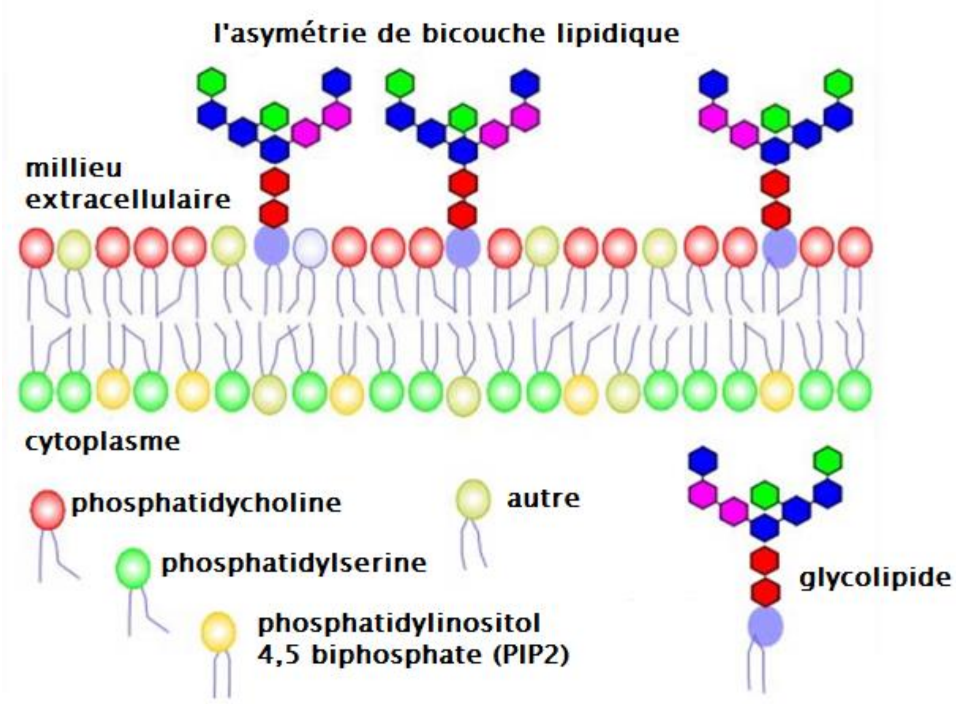
<u>The main membrane lipids</u> are phospholipids such as **phosphatidylcholine, phosphatidylserine, phosphatidyl ethylamine, phosphatidylinositol, phosphatidic acid** which are based on phosphatidic acid, in which two of the hydroxyl groups are esterified with fatty acids and also having a component in the polar group - phosphate.

Considering this composition we can say that lipid molecules are amphipathic or amphoteric having a hydrophilic polar terminal group represented by a polar group and a hydrophobic end, represented by two fatty acid chains.

Due to their amphipathic character, lipid molecules are structured in cell membranes as a phospholipid bilayer, with the polar ends facing the water molecules and the nonpolar (hydrophobic) tails buried within each other.

Lipid molecules are small. About $5.10^6/\mu m^2$ phospholipid molecules are contained in the bilayer molecules and the thickness of the layer is 40 Å.

The composition of the cholesterol membrane includes cholesterol in smaller proportions (10-30%), glycolipids (0-12%). In particular, glycolipids are attached to the outer surface of the membrane



Cell type	proteins (%)	lipids (%)	carbohydrates (%)
erythrocytes	49	43	8
hepatocytes	54	36	10
myelin sheath	18	79	3

CELL MEMBRANE STRUCTURE: MEMBRANE PROTEINS

Protein macromolecules are inserted into phospholipid bilayer membranes and give them specific properties. Depending on their type, the bilayer can be fixed by electrostatic forces, hydrophobic or hydrophilic bonds.

There is a wide variety of proteins in the composition of membranes.

They form the active element of the membrane.

Functions of membrane proteins:

- It plays the role of enzyme

- Enter the ion channel composition
- They work as carriers
- They are receptors for different hormones

Depending on their location, membrane proteins can be grouped into:

- Extrinsic (peripheral) proteins located on the surface of the doubler where they penetrate it for a short distance through hydrophobic bonds (which penetrate the membrane)
- Intrinsic (complete) proteins, which are deeply embedded in the bilayer or even through it from one side to the other. They are strongly hydrophobic and therefore difficult to isolate (necessary for strong detergents). The amino acids in the composition of these proteins were concentrated through hydrophobic Interio groups, forming bonds with the hydrophobic and hydrophilic phospholipid molecules that make up the enzyme to the outside.

Physical properties of the membrane

Thickness : 40-75Å

The electrical resistance of the surface unit is 1-100k Ω/cm^2 .

The high value of this resistance is motivated by the fact that most of the cell membrane is composed of lipid molecules that have a strong insulating role.

The ionic conductance is: $g = g_{Na^+} + g_{K^+} + g_{Cl^-} + g_{other\ ions}$

It is given by the sum of the membrane ionic conductances for the major permanent ions (that can cross the membrane) that pass through the channel of ion-complete protein formations)

The electrical capacity of the unit area is high: **0.5-8 μF/cm^2**

Physical characteristics of natural membranes

Property	**Value**
The natural thickness of the membrane (Made by electron microscopy)	40 ÷130Å
Myelin thickness (performed by XRD)	40 ÷85Å
Resistance	$10^{2} \div 10^{5}$ Ω/ cm
The ability	0.5 ÷1.3 mF/cm^2
The resting potential difference	10 ÷88mV
Refractive index	1.55
Surface tension	$3.10^{-5} \div 3.10^{-3}$ N/m
Water permeability	25÷28

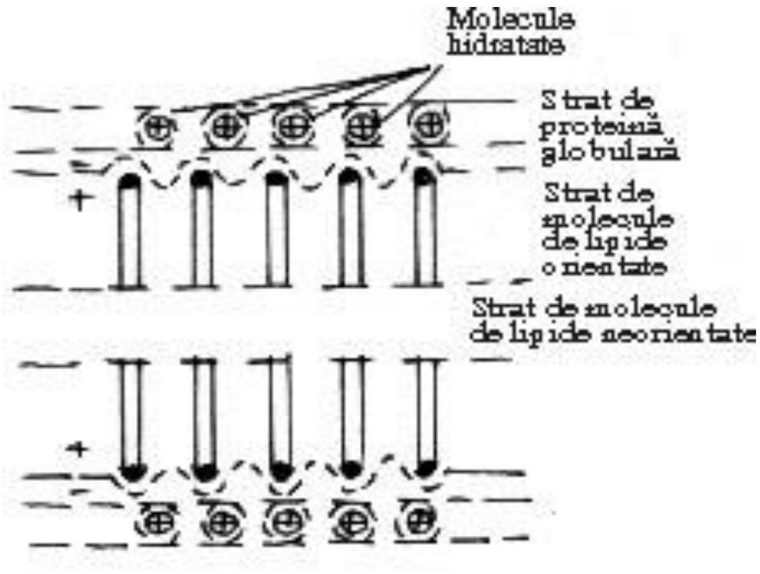


Figure: the structure of cell membranes of simple lipids

Today we accept the scheme of FN Harvey and JJ Danielli (1941) according to which **the cell membrane consists of two layers of oriented lipid molecules, the hydrophilic ends of which can move in and out of the cell** (see figure).

The surface tension of the cell is low, which corresponds to the hypothesis that the membrane is covered on both sides with a layer of globular proteins.

The contact between proteins and lipids, the surface tension of the cell is however weaker.

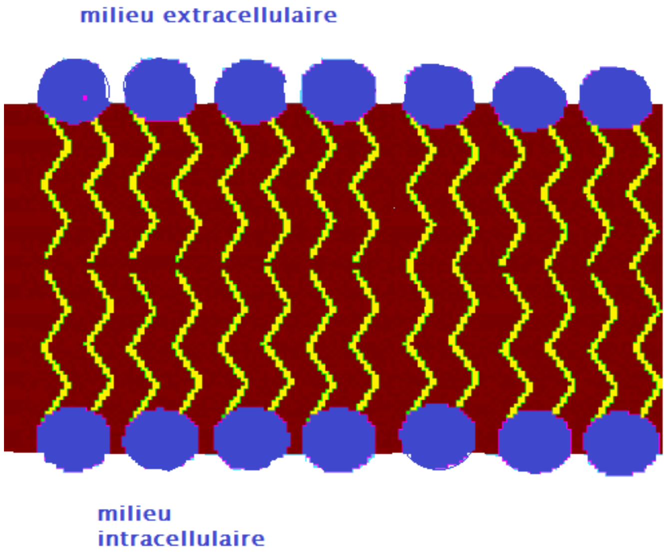
Layer of proteins containing molecules hydrated from place to place; the ends facing the layer of lipid molecules are ionized proteins. Molecules from the extracellular solution make their way through the gap between the lipid molecules and collide with them. This orientation breaks down lipids that can form a pore. Therefore, the substance from outside, which has a higher kinetic energy than the energetic protoplasmic membrane, can penetrate inside the cell. The energy of the substance leaving the cell must be greater than that of the lipid molecules in order to disrupt the facing layer.

Characteristic and paradoxical is the phenomenon of more accessible penetration of crystalloid substances with relatively large molecules (e.g. urea) than that of metallic ions (such as alkaline earth or alkaline). The explanation is, on the one hand, the hydration of ions, on the other hand, the existence of electric charges on the membranes of life. These charges have a multiple origin: electrolytic dissociation of membrane constituents, adsorption of membrane ions, etc. According to some authors (Ling C), the cell membrane could function to some extent as an ion exchanger. Under the influence of an electric current, the permeability of the colloidal membrane of both living (such as the permeability of fish gills) and artificial collodion (EA) Pora changes.

MEMBRANE MODELS

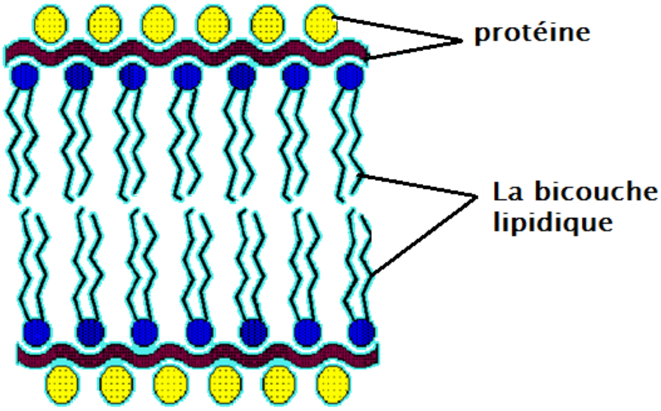
- **Gorter and Grendel's membrane theory – 1925**
- **The Davson–Danielli model - 1935**
- **The Singer model – 1971**
- **The Singer–Nicolson model - 1972**

Gorter-Grandel models were proposed in 1925 - for the first time put on a membrane with two layers of compound phospholipids.



Danieli and Davson models developed in 1935 when they took the double layer idea from Gorter and Grendel's model and introduced a new idea; that there are also protein macromolecules in the composition of the membranes. The proteins are considered to be arranged in a continuous layer on the surface of the bilayer.

Until Robertson in 1960, proteins were thought to reside in continuous bilayer surface layers of phospholipids.



3. SINGER proposed the SINGER model in 1971, based on the concept read by Danielli-Davson, it considers that proteins are found throughout the thickness of the membrane.

This model was developed and became the improved **fluid mosaic model**.

The phospholipid bilayer is considered to be a two-dimensional liquid. Proteins and lipids have a certain degree of mobility and diffusion in the membrane.

The model is based on experimental results. Frozen membrane studies by electron microscopy show the location of proteins in liquid mosaics, and modern spectroscopy methods guarantee the mobility of proteins and lipids in the membrane.

The Singer Fluid Mosaic model provides data on the structure, arrangement, and mobility of cell membrane proteins.

Singer distinguishes two types of membrane proteins: membrane and peripheral.

Peripheral proteins can be solubilized in aqueous solutions (eg, they are no different from other proteins that are soluble in water. They can be separated without destroying the membrane structure.

Integral proteins are difficult to isolate, they are not soluble, they have a pronounced hydrophobic character.

Amino acids with nonpolar residues in proteins are concentrated at one end of the macromolecule in membrane lipids. And an enzymatic part of the macromolecule is on the surface of the membrane and is accessible from the aqueous medium.

SINGER-NICHOLSON model proposed in 1972 is also called the lipoprotein liquid mosaic model. It is a uniformly accepted pattern today.

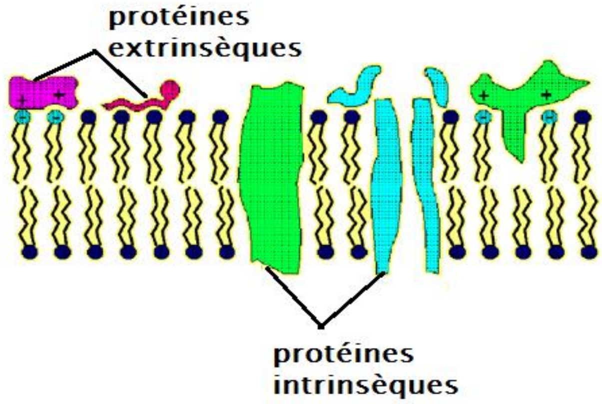
The model is based on the layer of phospholipids and proteins; only the location of the molcules differs.

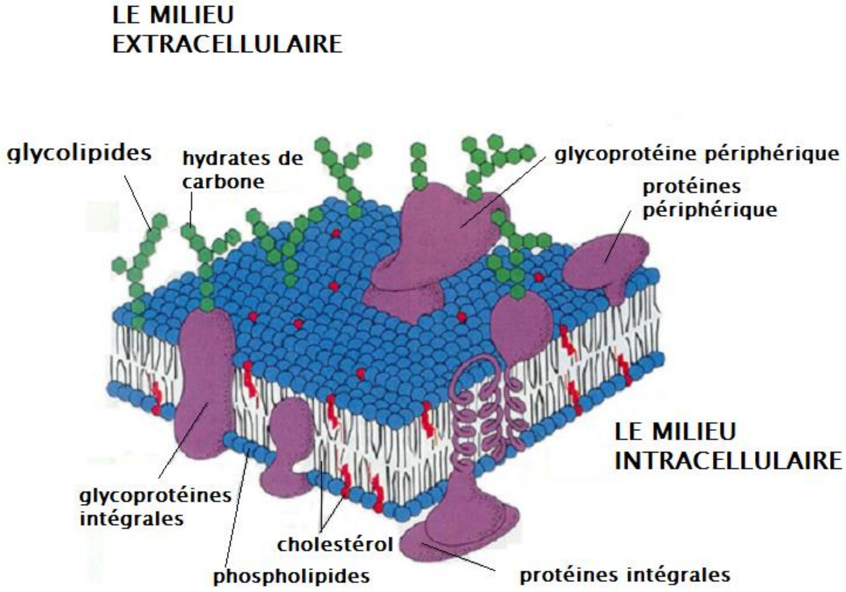
According to this model, proteins are found throughout the thickness of the double layer and posess a fluid consistency. The proteins are devided in two groupes:

- **Extrinsics** that can be found :
  - on the outer side of the membrane, playing the role of enzymes
  - on its internal side and represents the support of the internal cytoskeleton
- **Intrinsic**:

  Type I, outer portions - act as receptors

  Type II, crossing the membrane from one side to the other - in the form of ion channels.





Donnan balance

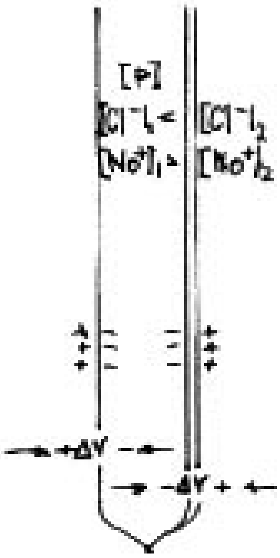


Figure 2: **Donnan equilibrium**

FG Donnan finds that, if one of the ions cannot pass through the membrane being, for example, macromolecular, the ions do not diffuse, but are distributed unequally on its two sides. In a bowl divided into two compartments by a collodion membrane, Congo red (a colloidal electrolyte that releases non-diffusing R- ions) is introduced into one of the compartments and NaCl into the other.

We see (Figure 2) that the Cl^- ions are in equilibrium in the two compartments when the concentration is unequal, but the product of the diffusion ion concentration has the same value on both sides of the membrane: $[Na^+]_I \cdot [Cl^-]_I = [Na^+]_H \cdot [Cl^-]_H$

Under certain conditions, Donnan equilibrium can cause chemical reactions (osmolysis), for example hydrolysis through the uneven distribution of H^+ and OH^- ions from the decomposition of water.

It changes the osmotic pressure between the two compartments. N. Barbulescu (1949) showed that the membrane has a specific role in this process, depending on the balance of qualities.

The membrane allows the passage of the ion diffusion rate is not equal in both directions. If we denote by [x] the concentration of Congo red, we can write the relation: $\frac{[NaCl]_H - [x]}{[x]} = 1 + K\frac{[NaCl]_I}{[NaCl]_H}$

Where K is the variable coefficient of the membrane from one situation to another.

Cerebrospinal fluid, edema fluid, aqueous humor of the eye are produced by dialysis of blood resulting in membrane balance.

In the sorption theory (phase theory) protoplasm is considered to be a phase that has a number of physicochemical characteristics similar to coacervates (DN Nasanov, 1945 AS Trosin, 1956 VI Alexandrov, 1940). The level of sorption is the ability of solubility, adsorption, chemical absorption (chemisorption) of protoplasm to a given substance. The level of the sorption cell is higher than a certain substance, the amount of the substance entering the cell is increased. When the surrounding solution is diluted, the permeability of the protoplasm may be greater. The substances contained in the solutions are more concentrated than the adsorbed coacervate, which is explained by the fact that the substances present in the concentrated solution are poorly soluble in the water connected to the coacervate.

The study of permeability cannot be limited to the entry or exit of substances through the cell membrane, but must be supplemented with qualitative and quantitative research exchanges between the nucleus and cytoplasm and in general the exchange membranes of various cell organs. Under normal conditions, the penetration of liquids from the cytoplasm into the nucleus in their passage from the nucleus to the cytoplasm is regulated so that the osmotic balance is established between the nucleus and the cytoplasm; the core retains its shape and turgidity. The phenomenon of plasmolysis takes place in the nucleus (by losing water, the volume decreases). According to research by Shapiro and Beck (1936) on immature eggs of Asterias forbesii, nuclear substances are osmotically more active than in the cytoplasm. By placing the egg in 80% seawater solution, the nucleus absorbs more water and slowly reaches osmotic equilibrium with the external environment of the whole cell.

The osmotic balance between the nucleus and the cytoplasm is still very unstable: a very small hypotonicity of the cytoplasm leads to the penetration of liquids into the nucleus. When water enters the nucleus, two phenomena can occur, either impregnation through intercellular water penetration, or vacuolation.

The flattened cores of Spyrogyra can increase their volume by 64%. once put in water.

TRANSMEMBRANE TRANSPORT

The passage of substances through biological membranes is one of their most important functions. Transport tends to occur spontaneously from a higher to a lower concentration and for electrically charged particles there is a tendency to move ahead of the membrane which is charged with the opposite sign charge.

The thermodynamic force underlying transport is electrochemical potential gradient:

$$\mu_i = \mu_{i0} + R.T.\ln c_i + z_i.F.E$$

If we study the process in terms of energy: the change in free energy during the transport of one mole of substance from compartment 1 to compartment 2 is:

One of the criteria for classifying transmembrane transport is energy:

$$\Delta G_{1\to 2} = R.T.\ln\frac{c_2}{c_1} + z.F.(E_2 - E_1)$$

Passive transport - is without energy consumption - Gibbs free energy = exergonic process, to reduce the electrochemical gradient (eg anabolism = Phase of metabolism in which the nutrients introduced into the body are transformed into its own substance, assimilation).

Active transport – it is an endergonic process (with absorption of free energy) it cannot occur spontaneously; increases the thermodynamic force. (For example, catabolism = biological process of transformation of complex, specific substances into simple and non-specific substances, which the body eliminates, disassimilation.

CLASSIFICATION AND DEVELOPMENT MECHANISMS OF ACTIVE AND PASSIVE TRANSMEMBRANE TRANSPORT

PASSIVE TRANSMEMBRANE TRANSPORT

- Free diffusion
- Ion channels
- Facilitated diffusion
- Active transmembrane transport:
- Sodium/potassium pump (dependent on Na/K ATPase)
- Gastric mucosal pump
- Coupled transport

PASSIVE transmembrane transport is a process that occurs spontaneously, without energy consumption, to reduce the electrochemical gradient of the transported species.

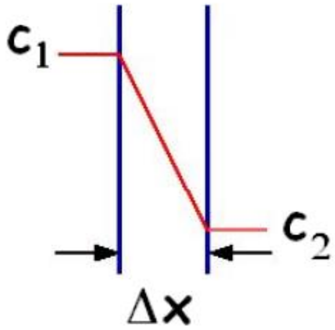
The process is based on the diffusion of ions and small molecules through the cell membrane with the release of Gibbs free energy ($\Delta G<0$). The tendency of passive transport is to bring the system closer to equilibrium.

Passive transport can occur in different ways depending on the type of scattering particles.

- Free diffusion
- Ion channels
- Facilitated diffusion

TRANSMEMBRANE PASSIVE TRANSPORT:

FREE DISTRIBUTION



Only molecules of very fat-soluble substances (benzene), gases (O_2, CO_2), small polar molecules (water, ethanol) can pass through the membrane due to passive transport carried out by free diffusion.

The process follows Fick's law: $\frac{dv}{dt} = -D.S.\frac{dc}{dx}$

The ratio of the diffusion coefficient D to the membrane thickness

It is called **permeability** $P = \frac{D}{\Delta x}$, $[P]_{CGS} = 1\frac{cm}{s}$

It has different values depending on the transported material

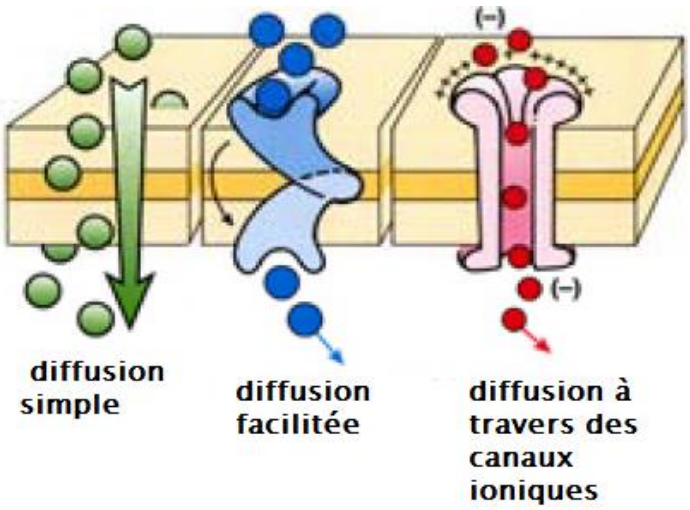
The amount of passively diffusing substance in section S of the membrane is given by: $\frac{\Delta n}{\Delta t} = -P.S.(c_2 - c_1)$

The membrane permeability of diffusing molecules varies inversely with the diameter of the molecule: P ~1/ ϕ.

The more fat-soluble the substance; therefore characterized by a partition coefficient PLIP: the easier the water will cross the membrane.

Through this mechanism ions cannot pass because the relative permittivity in the double layer vacuum ($\varepsilon r = 2$) is much lower than that entering the extracellular fluid, which are aqueous solutions $\varepsilon r = 81$, the Coulomb interaction force is stronger inside membrane.

PASSIVE TRANSMEMBRANE TRANSPORT THROUGH ION CHANNELS



Using this method, ions can pass through the membrane as electrically charged particles.

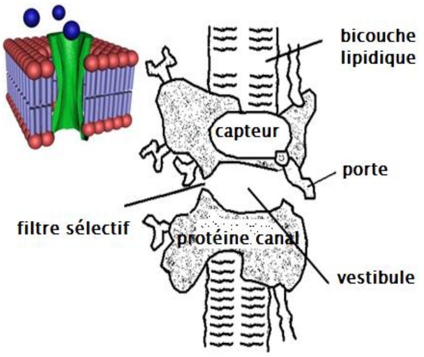
At the basis of this transport are either protein structures or integral proteins that cross the membrane from one side to the other, forming ion channels inside that are generally permeable in both directions. The direction is dictated by the electrochemical gradient.

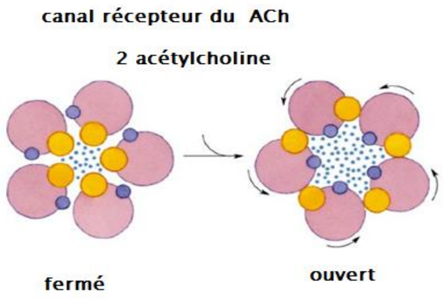
Ion channels are selective formations in general, they allow the passage of a small number of ionic species.

Cation channels are much more common, they do not allow ions to pass through, with the entrance repelling the negative charge. For charges of the same sign, selectivity refers to the size of the ion.

Ion channels are composed of:

- **selectivity filter** – which selects ions according to size criteria
- **vestibule** - passage of ions
- **the gate,** which is in two conformational states: allowing and disallowing the passage of ions through the channel
- **the sensor** that controls the door





Depending on how it is regulated, opening channels are distinguished:

Voltage-gated channels: the command is triggered by the change in the transmembrane potential. Examples of cation channels: Na^+, K^+, Ca^{+2}, excitable cell membrane.

chemically controlled channels, in which the opening of the channel mouth is caused by the binding of a chemical messenger.

Example of ***chemically controlled channels*** Acetylcholine receptor channel: Ach muscle junction of neuro postsynaptic membrane.

PASSIVE MEMBRANE TRANSPORT BY FACILITATED DIFFUSION

Small hydrophobic molecules can cross the membrane by diffusion of free ions passing through ion channels, but hydrophilic, polar molecules cannot use either of these pathways. The passage of substances through the essentially hydrophilic membrane via the mediation of carrier transport molecules is called the FACILITATED DIFFUSION mechanism.

Transporters are specialized molecules capable of distinguishing between two isomers of the same substance. The transporter recognizes the molecule that is specific and promotes its transport to reduce its electrochemical gradient, i.e. from high concentration to low concentration.

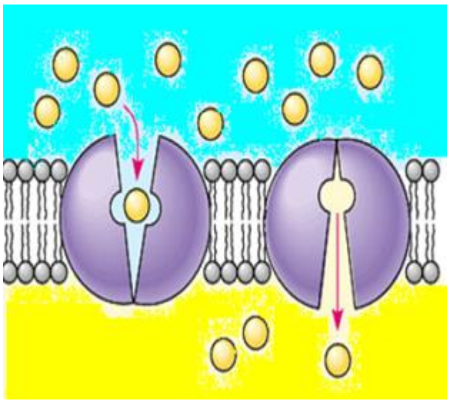
There are two distinct conformational states in which you can find support:

- A state in which the binding site of the transported molecule is located on one side of the membrane
- Another position that is on its face 2

After the binding of the molecule to be transported on the surface of the membrane where its concentration is higher ($c1 > c2$), a conformational change of the support mutation obtained in the binding site on the other side of the membrane takes place, followed by the release of the molecule at this site transported.

The efficiency of facilitated diffusion is much lower than ion channels. Thus, if the ion channel can allow the passage of 108 ions/s, in the glucose diffusion process facilitated by the erythrocyte membrane, the medium is capable of transporting 300 Molec/s.

Glucose crosses the erythrocyte membrane at a much higher rate than the corresponding free diffusion, facilitated by transporter proteins.



The amount of facilitated substance that diffuses per unit of time is as follows:

equation of facilitated diffusion

$$\frac{\Delta v}{\Delta t} = -k.P.S.\left(\frac{c_2}{c_2+k} - \frac{c_1}{c_1+k}\right)$$

particular case

$$c_1, c_2 \langle\langle\ k \Rightarrow \Delta v = -k.P.S.(c_2 - c_1).\Delta t$$

$$c_1, c_2 \rangle\rangle\ k \Rightarrow \Delta v = 0$$

c1 , c2<<k - low concentrations apply Fick's law.

c1c2 >>k - saturation occurs in high concentrations and the transport stops

ACTIVE TRANSPORT

Any tissue is a group of cells surrounded by an interstitial fluid called external. The continuous phase of the cell protoplasm, in its entirety, is an intracellular fluid. The composition of these fluids has an important role of inorganic sodium (Na^+) and potassium (K^+) cations. Although the molar concentrations of the two liquids are similar, they show significant differences in ionic concentrations. The concentration of K^+ ions in the intracellular fluid is greater than that of Na^+ ions. The concentration of Na^+ ions in the interstitial fluid is greater than that of K^+ ions. But the intracellular fluid contains other organic and inorganic macromolecular Anions A-, and the interstitial fluid has a high concentration of Cl^- ions, in addition to the high concentration of Na^+ ions.

The cell membrane, a complex structure described above, separates the different electrical charges of the two liquids, acting as a dielectric. Negative charges are distributed on the inside of the membrane and positive charges on the outside. Therefore, together with the difference in the concentration of ions of different types, there is also a difference in electric potential, an electric voltage called membrane voltage potential (UM) or resting potential. The membrane with adjacent ionic charges constitutes a capacitor with a relatively large capacity, the thickness of the membrane (dielectric) is less than approximately 100 A.

Cephalopod nerve fibers have a membrane capacitance of about 1 mF/cm2; capacitance of frog skeletal muscle fibers is 10 mF/cm2 and membrane potential = -90 mV UM. There is an essential difference between a physical dielectric capacitor and the cell membrane. If a given dielectric behaves the same at any electrical charge, the permeability of the cell membrane is different for ions of the same charge. The permeability P of the membrane to K^+ ions is approximately one hundred times greater than to Na^+ ions. In the skeleton of amphibian muscles, the permeability to K^+ ions is PK»10-6 cm/s, while PNa»2*10-6 cm/s. The water permeability of a layer of the same thickness as the membrane (100 A) for K^+ ions is P»10 cm/s, which is ten million times greater than the PK permeability of the cell membrane. These values clearly express that the cell membrane limits the flow of ions. Therefore, the pore diameter was assumed to be intermediate between the diameter of the hydrated K^+ ion (2.2 Å) and the diameter of the Na^+ ion (3.4 Å).

The potential difference between adjacent layers that make up the membrane with a membrane potential of the ionic equilibrium potential. The sum of the membrane potential UM and the potential of identical ions on both sides of the membrane is called the electrochemical potential.

The value of the equilibrium potential of the ions is given by the Nernst relation, which for potassium ions is written: $U_K = \frac{RT}{F} \ln \frac{[K^+]ext.}{[K^+]\text{int}.}$

By decimal logarithms we obtain in millivolts

$$U_K = 60 \log \frac{[K^+] ext.}{[K^+] \text{int}.}$$

Although the membrane permeability for K^+ ions is higher than for Na^+ ions; the latter constantly move from the outside to the inside of the cell. However, the concentration of Na^+ ions inside the cell remains at a low level in living cells. This means that there is a mechanism by which Na^+ ions are transported from the inside to the outside of the cell; from a low concentration to a high concentration; from a low to a high electrochemical potential.

When molecules and ions are transported against the electrochemical potential, the phenomenon is called active transport. The energy required for this transport comes from cellular metabolism. Active transport takes place when the energy metabolism of the cell remains intact. Not only Na^+ but also other ions are actively transported. Thus, an active transport of H^+ takes place in the stomach mucosa. In the intestinal epithelium, there is an active transport of ions, water, glucose, fatty acids, amino acids. Active transport of ions and water occurs through the skin of the frog, and iodine actively accumulates in the thyroid cells.

Usually, when a Na^+ ion leaves the cell, a K^+ ion enters it. The active transport of Na^+ is called the Na^+ K^+ pump or simply the Na^+ pump (AL Hodgkin). The pump causes the membrane potential to remain constant and recover when altered by excitation. The mechanism at the molecular and submolecular level has not yet been explained; but there are plausible hypotheses. Adenosine triphosphate ATP molecules have been shown to be an energy source for active transport. For some researchers, active transport is due to the *carrier molecules* ; having a special affinity for certain ions, it combines with them in a reversible manner. The complex would be fat-soluble, it would enter the cell where it would dissociate (Hodgkin). At the same time, the other ions of the cell combine with the carrier molecule that crosses the membrane. Outside the membrane the ions separate from the transporter. In this way, free diffusion would combine with active transport in both directions. In any case; active transport also involves enzymes that hydrolyze ATP (ATP-ases) fixed at the cell surface and stimulated by Na^+, K^+ and other ions (JC Skou, 1961).

STRUCTURAL THEORY

According to E. Macovschi, the theories proposed for cell permeability are inadmissible because they ignore the intervention of the biological activity of the contact zone itself between the cell and the external environment. As mentioned, the protoplasm would form a unitary, spongy or generic structure, and the contact area would not be a proper membrane, but a semi-membranous one, which has no internal cell surface distinct from living matter.

The metabolic activity of living matter is expressed directly in the exchange of matter with the outside. We can talk about membranes in the classical sense of the term when we study the transport of substances between multicellular organisms and the external environment or between departments of the same body. These membranes are traversed by substances according to Fick's diffusion law or Freundlich's (isothermal) adsorption law. Quantitatively, transport phenomena in the brachial membrane of fish can be reproduced in the laboratory using a thin sheet of collodion artificial gills.

Jacovschi's (1965) comparative review of membrane theory, sorption theory, and structure theory states:

- Each theory attributes a different nature to protoplasm (protoplasmic fluid, protoplasmic coacervate, protoplasmic together)
- Each takes into account differently the qualities and state of protoplasmic water involved in transport phenomena (free water, bound water, water integrated into the structure of living matter - imbibing of living water with free water of non-living matter).).
- Each theory is based on different views on the electron state of protoplasm (total proteins dissolved or dissociated, bound adsorbed colloids dissociate in water integrated into the structure of living colloids adsorbed by living matter dissolved in the nevus state and matter - dissolved in the separated state of water of living matter, free water of non-living matter).

The notion of active transport was introduced by Overton who observed that living cells are able to maintain constant concentration differences between the cytoplasm and the extracellular environment for species that can cross the membrane (which could equalize their concentrations on both sides of the membrane)

Active transport is one of the most important processes occurring in living matter, requiring energy consumption (it is endergonic: $G\Delta < 0$) as an electrochemical gradient that results in an increase in transported species.

Active transport can be:

- PRIMARY, when coupled with the exergonic reaction (ATP hydrolysis)
- EXTERNAL when coupled with the simultaneous transport of other species, to reduce their electrochemical gradient - consequent passive exergonic flow of the substance

($\Delta G<0$)

Depending on the passive translocation direction of the two species:

- **Symport or cotransport** - if both species are transported at the same time, in the same direction
- **Antiport or exchange**, if the species are transported in opposite directions

	Transport velocity (Ions/s)	**Density (ions/μm^2)**
Ion channels	10^8	300-2000
Ion pumps	10^2 - 10^3	8000

TRANSMEMBRANE TRANSPORT ACTIVITIES:

Sodium/potassium pump (Na/K-dependent ATPase)

It is responsable for the imbalance of Na^+, K^+, Cl^- ion concentrations.

Inside the cell:

$[Na^+]$ ~10 mM, $[K^+]$ ~140 mM, $[Cl^-]$ ~5 mM

Outside the cell:

$[Na^+]$ ~140 mM, $[K^+]$ ~5 mM, $[Cl^-]$ ~100 mM

The electric gradient and the concentration gradient are compensated by the K^+ and Cl^- : $E_{int} - E_{ext} = -90$ mV

Both gradients result in increased passive flux of Na^+ from outside the cell to inside the cell. This passive Na^+ compensated flow is offset by the activity of the Na/K pump – which pumps Na^+ ions inside the cell. ATPase pump consumes Na/K ATPase = Na/K dependent.

For one molecule of ATP hydrolysis, three ions Na^+ are removed outside and in parallel enter the cell K^+ (2 ions) and goes Cl^- (1 ion).

Adenosine triphosphate ATP - ($C_{10}H_{16}N_5O_{13}P_3$) is part of the nucleic acids DNA and RNA, consisting of triphosphate, adenine and ribose (a pentose). The battery is required for energy storage and cell-by-cell energy conversion based on metabolic needs.

Na+/K+-dependent ATPase permeates the thickness of the cell membrane. It has a molecular weight of 3.10^5 and consists of two large protein subunits and one small subunit.

The enzyme has two conformations E1 and E2 with high affinity for Na^+ or K^+.

In addition, Na^+ and K^+ ions require an ATP and Ma2+ pump to function, and certain steroids, such as extracellular ouabain, prevent this pump from functioning.

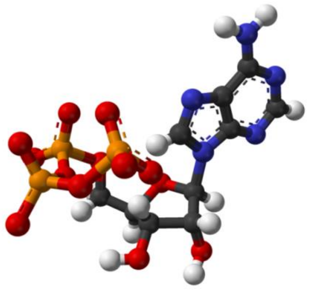
The active transport mechanism can be schematized as follows:

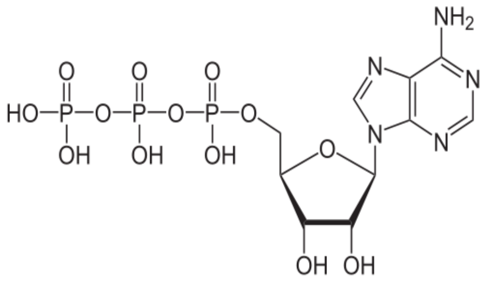
$$E_1 + Na^+_{\text{int}} + ATP \overset{Mg^{2^+}}{\rightarrow} Na - E_1 \approx P + ADP \quad (on\ the\ inferior\ part)$$
$$Na - E_1 \approx F \rightarrow Na - E_2 \approx P(Na^+\ is\ removed\ on\ the\ inferior\ part)$$
$$Na - E_2 \approx P + K^+_{ext} + H_2O \rightarrow E_1 + K^+_{\text{int}} + Na^+_{ext} + HPO_4^{2-}$$

ADENOSINE TRIPHOSPHATE (ATP)

Adenosine triphosphate (ATP) ($C_{10}H_{16}N_5O_{13}P_3$) is a nucleoside triphosphate used in the cell as a coenzyme. It is also called a unit of the molecular scheme of intracellular energy transfer.

ATP transports chemical energy between cellular metabolic processes.





ATPase is the end product in the process of phosphorylation, cellular respiration, or fermentation, and is used by enzymes and structural proteins in many cellular processes, including biosynthetic reactions, motility, and cell division.

A molecule of ATPase contains three phosphate groups and is produced by a wide variety of enzymes, including ATP synthase from adenosine diphosphate (ADP) and adenosine monophosphate (AMP) and various phosphate group donors.

The main mechanisms of ATPase biosynthesis are the level of substrate phosphorylation, oxidative phosphorylation in cellular respiration in the process of photosynthesis.

ATPase was discovered in 1929 by Karl Lohmann, Fiske and Y. Subbarao at Harvard Medical School, but its correct structure was determined a few years later by Fritz Lipmann in 1941. It was proposed as the main cellular energy transport molecule.

It has also been proposed as the main energy transfer molecule as an intermediate cell between energy yield and energy-demanding endergonic and exergonic reactions.

It was first synthesized artificially in 1948 by Alexander Todd.

TRANSMEMBRANAR ACTIVITIES

GASTRIC MUCOSA PUMP

It is involved in the gastric secretion of hydrochloric acid. Firstly, the transport of H^+ ions from the cells of the gastric mucosa with pH = 7 in the gastric juice with pH = 2. Cl^- ions go in the same direction as the transport of H^+ ions. If we ignore transmembrane potentials, the energy required for this transport by gastric lining cells (GLC) of H^+ into gastric juice (GJ) can be calculated using the following equation:

$$\Delta G_{CMG \to SG} = RT \ln \frac{\left[H^+\right]_{SG}}{\left[H^+\right]_{CMG}} = 5{,}92 \log \frac{10^{-2}}{10^{-7}} \approx 29 kJ/mol$$

The energy released by the hydrolysis of one mole of ATP, from the point of view of the organism, is :

ΔGs=-45kJ/mol

The hydrolysis of one ATP molecule provides enough energy for the transport of H^+ ions under these conditions.

In the cells of the gastric mucosa, the excess of OH^- ions

CO_2 is neutralized by a reaction catalyzed by carbonic anhydrase:

$$H_2O \leftrightarrow HO^- + H^+ \quad �, H^+ \rightarrow SG \text{ (transported outside)}$$

$$OH^- + CO_2 \xrightarrow{\text{anhydrase carbonique}} HCO_3^-$$

$$Cl^-(\text{int}) \rightarrow Cl^-(SG)$$

Inhibition of carbonic anhydrase by special drugs leads to inhibition of gastric secretion of HCl

TRANSMEMBRANE TRANSPORT ACTIVITIES: COUPLED TRANSPORT

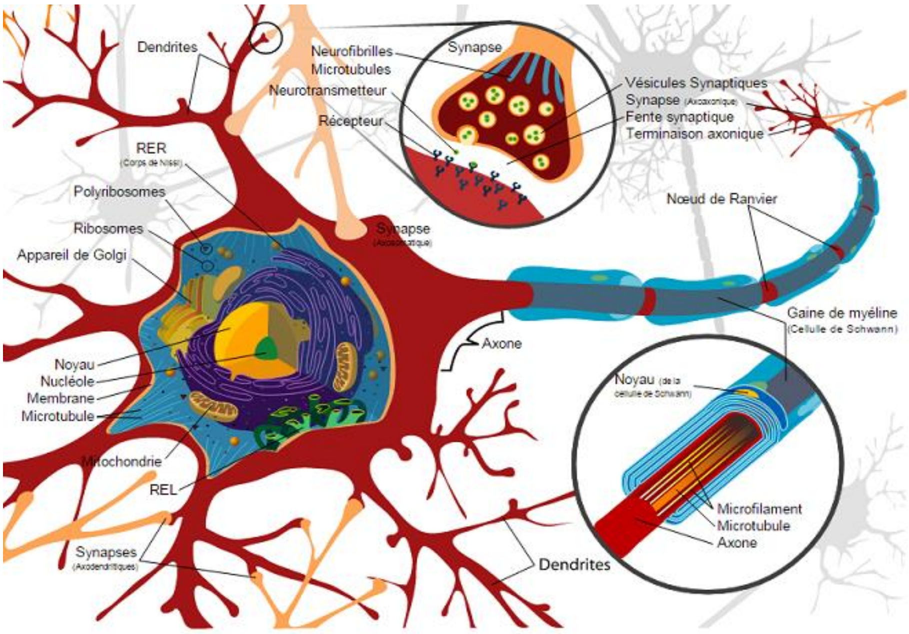
Glucose clearance against a concentration gradient in the glomerulus and renal tubules of the blood filtrate is coupled to Na^+ transport. So is the transport of amino acids through the air (lymph) into the cells.

This coupled transport is carried out by enzymes that have both Na^+ and amino acid (or glucose) sites on the same side.

Na^+ binding increases the affinity of the carrier for the amino acid inside the cell by diffusion where the concentration of Na^+ is low, Na^+ dissociates from the complex with the carrier obtained in the release of amino acids inside. The increase in the transport-related chemical potential within the amino acid is overcompensated by the transport-related energy release chemical potential of Na+ ions inside the cell.

SYNAPTIC TRANSMISSION

Structure and function of electrical synapses, Chemical structure and description of chemical synaptic transmission



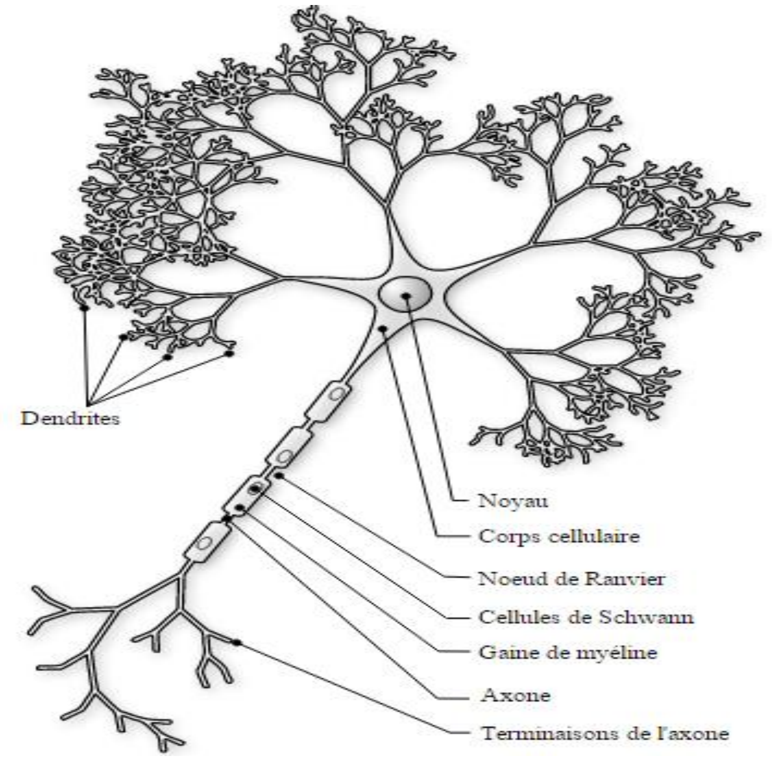
The NEURON consists of:

- a body called ***PERICARYON*** or cell body or **SOMA,**
- two types of extensions: **single AXONE** , which conducts the centrifugal action potential
- **dendrites** , which average 7,000 per neuron and conduct centripetal action potentials

The morphology, location, and number of these extensions, as well as the shape of the soma, vary and contribute to the definition of different morphological families of neurons.

For example, there are unipolar or multipolar neurons.

The diameter of the neuron body varies depending on their type, from 5 to 120 µm. It contains the nucleus, stuck in interphase and therefore unable to divide, and the cytoplasm. In the cytoplasm are the rough endoplasmic reticulum (forming the *Nissl bodies* of histologists), the Golgi apparatus, mitochondria, and neurofilaments that join together to form neurofibrils.



Extensions are of two types: **the axon** - single, and **the dendrites** .

Axon (or nerve fiber) has a diameter between 1 and 15 µm, its length varies from one millimeter to more than one meter. The emergence cone, a region extremely rich in microtubules, constitutes the origin of the axon.

It is also called the trigger zone because it participates in the genesis of the action potential. It describes a more or less long path (sometimes several meters) before it ends by branching **(** this is the terminal arborization).

Each branch ends in a swelling, the ***terminal button or synaptic button*** . However, “enfilades” of synaptic swellings are also observed on the same axonal segment constituting passing synapses. The plasma membrane of the axon, or axolemma, contains the axoplasm in continuity with the cytoplasm of the perikaryon. It consists of neurofilaments, microtubules and microvesicles (these are produced by the rough endoplasmic reticulum and the Golgi apparatus). Some axons are covered with a myelin sheath, made up of glial cells, Schwann cells from the peripheral nervous system, and oligodendrocytes from the central nervous system. It is estimated that about one in three axons is covered by myelin. Myelin sheathing of axons is actually discontinuous, separated by nodes of Ranvier, which are isolated from astrocytes. This coating allows for a higher rate of transmission of nerve information.

DENDRITS are numerous, short and highly branched from the origin. Sometimes they are covered with dendritic spines. Unlike the axon, they do not contain microvesicles that allow the transmission of information outside the neuron. The dendrite conducts the nerve impulse, induced at its extremity, to the cell body: it is an afferent extension.

Axons are gathered in bundles, themselves connected by connective tissue (endoneur and perineur) forming tracts and nerves.

SYNAPSE

Synaptic transmission can involve electrical or chemical mechanisms.

Synapses are:

- **electrical synapses**
- **chemical synapses**

A synapse is the functional junction of a neuron through which nerve impulses are transmitted from one cell to another.

The synapse consists of a presynaptic part, a synaptic cleft and a postsynaptic portions and unlike nerve fibers, the synapse transmits nerve impulses only to the presynaptic portion, so only unidirectional.

Depending on the size, there are three types of synapses:

- **Synaptic type I synapse** – with size: 300 Å
- **Synapse type II** - size: 200 Å - both with transmission through chemical mediators - acetylcholine, adrenaline, etc.)
- type III synapse empty synapse (electrical synapses without chemical mediators **)**

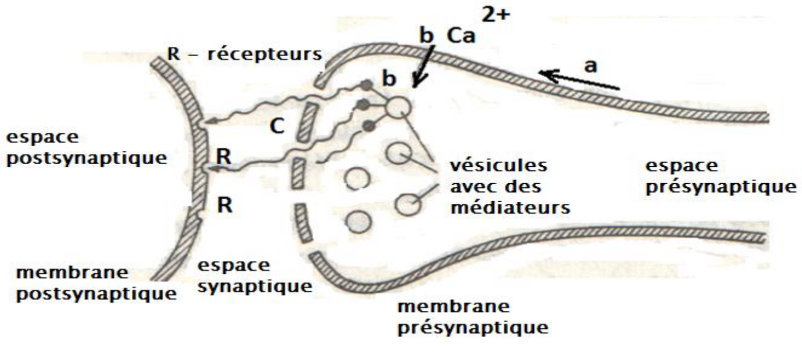


Diagram of a synapse

The PRESYNAPTIC TERMINATION is the axon terminal, the button that is part of a branch of the *terminal arbor* .

It is bounded by a junctional membrane in front and contains mitochondria and synaptic vesicles with chemical mediators.

The POSTSYNAPTIC PART is represented by a membrane corresponding to the contact area of the dendrite or parikaryon. At this level there are specific receptors for the chemical mediator.

The synaptic cleft contains an intersynaptic filamentous network that ensures the adhesion of the two membranes and that is crossed by the chemical mediator.

103-104 synapses exist on the surface of a neuron

The transition to excitation of the post-synaptic sector involves three essential steps:

1. Invasion of the synaptic knob by the nerve impulse – with depolarization propagating here causing membrane changes and release of mediators.

2. The release of the mediator in the synaptic cleft occurs under the influence of Ca^{2+} and Na^{+} ions entering after membrane depolarization. The release of the mediator is carried out in quantities of several thousand molecules similar to the contents of synaptic vesicles.

3. The transsynaptic propagation of the nerve impulse involves the crossing of the synaptic space released by the mediator, the action of the mediator on the postsynaptic receptors in the territory, which causes the depolarization of the postsynaptic membrane and the propagation of the nerve impulse.

Finally, an inactivation (enzymatic breakdown) of the mediator occurs and the post-synaptic membrane is able to receive a new message.

SYNAPTIC POTENTIAL

Synapses can be excitatory or inhibitory and **functionally characterized in relation to the specific mediator** (for example, acetylcholine in synaptic vesicles of cholinergic nerves, norepinephrine - in sympathetic nerves and the central nervous system - gamma aminobutyric acid, dopamine and serotonin, etc.).

- At **exciting synapses**, presynaptic excitation induces depolarization of the postsynaptic membrane.
- At **inhibitory synapses,** presynaptic excitation induces hyperpolarization.

The excitatory postsynaptic potential - EPSP - is generated after the depolarization of the postsynaptic membrane by the mediator, which makes it permeable to Na^+ . **The EPSP** has a duration of 10 ms. It has an amplitude proportional to the amount of mediator released, which allows spatial and temporal summation of stimuli. The action potential that propagates from the neuron is a depolarization of the postsynaptic membrane of about 10-30 mV.

The inhibitory postsynaptic potential - IPSP - is the expression of post-synaptic inhibition. It is generated under the action of the mediators of inhibitory effects that induce an increase in membrane permeability for K^+ and Cl^- ions, without influencing the permeability for Na^+ ions. This induces hyperpolarization of the postsynaptic membrane down to -5mV, indicating reduced excitability.

Neurons are the building blocks of the computer that is the brain, but instead of electrical impulses, the connection between these elements is through nerve impulses.

Depolarization of the postsynaptic membrane (a dendrite) is followed by a local action potential response R whose size depends on the amount of chemical mediator S by the equation: $R = k \lg S$, which propagates on the neuronal membrane only if it exceeds a certain threshold ($S \geq S_0$).

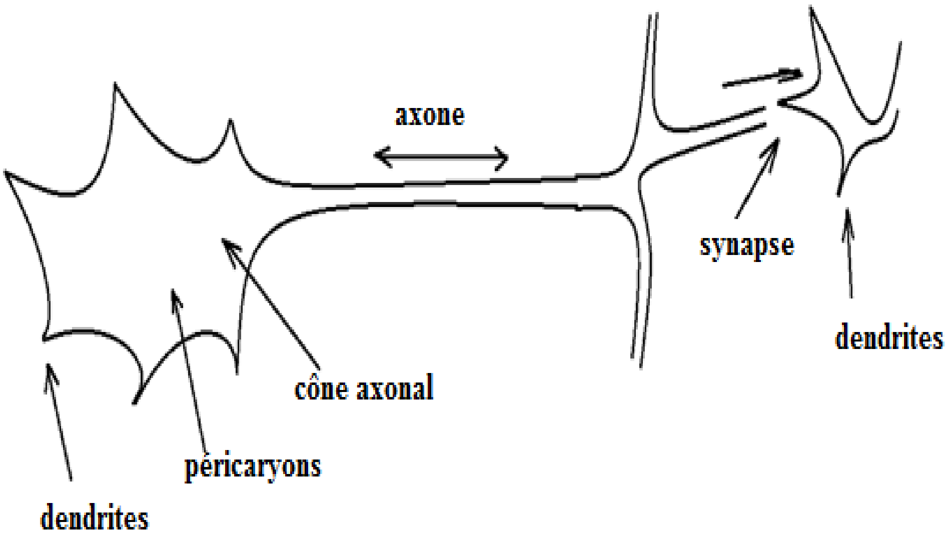
Action potentials, resulting in time Δt_2 from the axis of an axon at the level of excitatory and inhibitory synapses, gather at the level of the axonal cone.

If the depolarization exceeds a limit (the firing threshold), the neuron responds with a nerve impulse sent along the axon to the other neuron

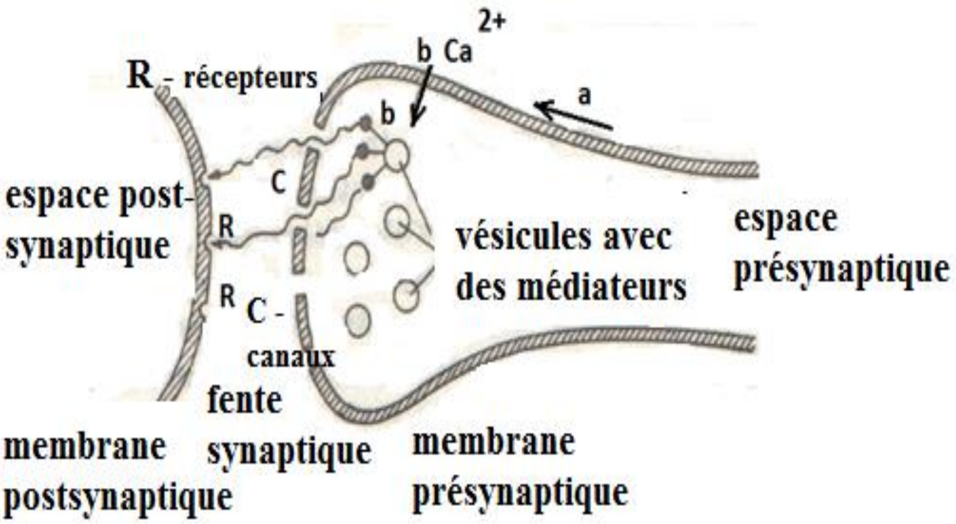
$\Delta t_2 \geq \Delta t_1$

Δt_1 is the time required for synaptic transmission for the influx of a nerve wave.

The neuron integrates the inputs received by its dendrites. The integral intensity for nerve input translates to the frequency of inputs sent along the axon.



Structure of the neuron



STRUCTURE OF SYNAPSES

Synapses can be:

- **electrical synapses**
- **chemical synapses**
-

Electrical synapse is less common than chemical synapse.

It is structurally very simple.

It is found in parts of the brain, between the smooth muscle cells or the cells between the retinal photoreceptors and the horizontal cells of the retina.

Electrical synapses are also called nexus or communicating macules.

Between the two membranes of the cell the distance is 2 to 2.7 nm, the contact between the membranes is made with the proteins in a channel-gap junction.

ELECTRICAL SYNAPSES

Due to this structure, **electrical signals are transmitted directly - through ion influxes - from the presynaptic cell to the postsynaptic one and therefore the electrical synapse does not introduce any delay.**

The meaning of the signals is: Electrical synapses are mostly bidirectional

The connection between the membrane of the presynaptic cell and that of the postsynaptic cell is achieved by a macromolecular structure in the form of bars, each composed of two macromolecular assemblies that come into contact in the environment between the two membranes.

Each cluster consists of six identical proteins called CONNEXON arranged at the periphery of a cylindrical structure with an outer diameter of 70 Å, positioned to form a pore center called CONNEXON.

This pore has a diameter of 10 to 20 Å and allows the passage of microparticles (ions and small molecules) - their molecular mass does not exceed 1500D.

Chemical synapse,has the following composition:

1. The presynaptic part containing the mitochondria and the presynaptic membrane (SRPM). In the synaptic side there are vesicles with chemical mediator.

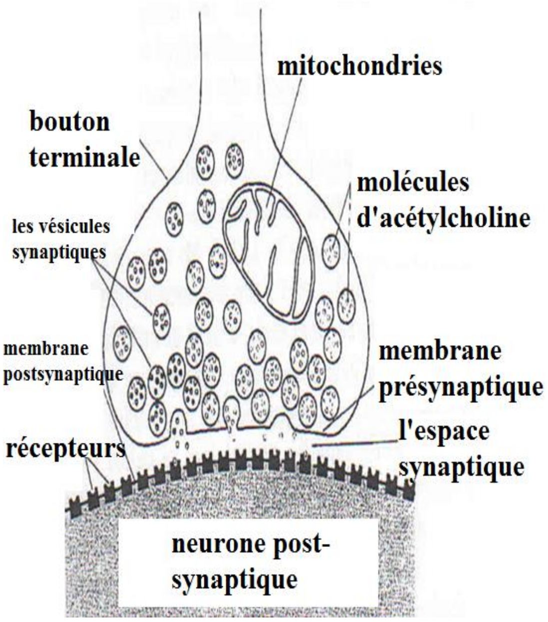
2. Synaptic cleft with gap size of 200 - 500 Å.

3. The postsynaptic part containing the postsynaptic membrane which is composed of chemically ordered ion channels

- In the case of **<u>chemical synapse,</u>**, **signal transmission is strictly unidirectional,**
- **The <u>chemical synapse,</u>**acts as a valve, and the distance between the two cell membranes is approximately: 20-50nm.
- **In the case of the <u>chemical synapse,</u> the transmission of signals takes place by means of a chemical mediator.**

At the level of the synapse between the two cells, there are important structural and functional differences that serve, on the one hand, as a signal transmitter (for the presynaptic neuron), on the other hand, as its receptors, in the case of the postsynaptic neuron, respectively of the muscle cell for motor muscle cell plate.

The presynaptic neuron presents **axonal branches** in the form of **terminal buttons** that contain a large number of **synaptic vesicles.**



Inside the vesicles are thousands of **chemical molecules** that are released into **the synaptic space** when the membrane depolarizes incoming action potentials, serving as a means of communication between cells at the synapse.

near **the presynaptic membrane** are high-density **mitochondria that provide an atpase necessary for the execution of energy-consuming processes.**

the postsynaptic neuron consists of dendrites or cell bodies of the postsynaptic cell.

its membrane has been called **the post-synaptic membrane** and contains **chemically operated ion channels** , which serve as receptors for the chemical mediator.

CHEMICAL SYNAPSE - TYPES OF CHEMICAL MEDIATORS

- **Acetylcholine: ACh :** the most common occur at excitatory synapses
- **GABA -** The fastest inhibitory synapses in all brain regions; sedatives, tranquilizers.
- **Dopamine** - Parkinson's disease, schizophrenia
- **Glutamate** - fast excitatory synapses in the brain and spinal cord
- **Adrenalin**
- **Norepinephrine**
- **Serotonin**
- **Histamine**
- **Glycine**

Acetylcholine is the first to be identified as a neurotransmitter in the central nervous system and at the level of the peripheral system.

CHEMICAL STRUCTURE :

Acetylcholine is an ester formed by the esterification of acetic acid and choline. Its ester-like structure is confirmed by IUPAC as: 2-acetyloxy-trimethyl ammonium chloride (chloride).

Acetylcholine was recognized in 1914 by Henry Hallett Dale, who discovered its action on the heart muscle. Otto Lewi confirms its function as a neurotransmitter and calls it vagusstoff because it is released from the vagus nerve.

Research has shown that ***acetylcholine*** *binds to cholinergic receptors in muscle fibers, which causes sodium ion channels to open.*

Sodium ions enter the cell, where they stimulate muscle contraction. Acetylcholine during the induction of muscle contraction, causes both the reduction of heart muscle contractions.

This is due to the difference in the structure of the receptors in the muscles and the heart. Acetylcholine also has activity in the brain (which is excitatory).

Biosynthesis: occurs in the cytoplasm of cholinergic neurons from choline and acetyl coenzyme A in the presence of the enzyme choline [4], (synthesized inside the neuron).

ACETYLCHOLINE

Metabolism:

Occurs in the synaptic cleft by a hydrolysis reaction catalyzed by acetylcholinesterase (the products are choline and acetic acid) or pseudocholinesterase

Storage: Renders synaptic vesicles in free form or protein complex

Release and fixation: ACh (free form) is released from vesicles permanently or when needed under the influence of nerve impulses. Regulation of this release occurs through the ligand receptor and physiological ions.

The types of receptors for acetylcholine (cholinergic receptors) are of two types:

- **Nicotinic receptors (nAChR)** receptor known as an "ionotropic" that mediates the nicotinic alkaloid.
- **The receptors are nAChR receptors** which form voltage-gated ion channels. They consist of five protein subunits: α, α, β, γ, δ. The subunits have a larger outer surface area, which will bind acetylcholine

Muscarinic receptors: muscarinic receptors are polypeptides with a mass of approximately 80,000 daltons. They are of several types: M1, M2, M3, M4, M5. These, when stimulated by acetylcholine or pharmacological agonists, have a stimulating effect

DOPAMINE

Dopamine is one of the main neurotransmitters in the nervous system, a substance that transmits information between neurons in the brain), the substance is involved in a variety of different activities (eg, controlling motility, muscle movement).

Background: Dopamine was synthesized by George Barger in 1910 with the help of his colleague James Ewens, Wellcome Laboratories in London [1]. It was named dopamine because it is a monoamine and its synthetic precursor is 3,4-dihydroxyphenylalanine (L-DOPA). The function of dopamine as a neurotransmitter was recognized in 1958 by Arvid Carlsson and Nils-Åke Hillarp at the Chemical Pharmacology Laboratory Heartland Sweden [2].

Dopamine biosynthesis is a two-step process, starting with the amino acid tyrosine. A second hydroxyl forming group is attached to the tyrosine forming levodopa or L-dopa. This process is catalyzed by the enzyme tyrosine hydroxylase. Dopamine is formed by removing the carboxylic acid from L-dopa, the reaction catalyzed by dopa decarboxylase.

GABA, or gamma-aminobutyric acid , is considered one of the most important central inhibitory mediators. The highest concentrations of GABA were found in the globus pallidus, hippocampus, substantia nigra, cerebellar nuclei, periaqueductal gray matter, caudate nucleus, medial thalamus.

Gamma-aminobutyric acid is a decarboxylation product of glutamic acid, closely related to the oxidative metabolism of carbohydrates, the central nervous system. The synthesis is carried out by the enzyme glutamate decarboxylase.

GABA cannot cross the blood-brain barrier (outside certain areas of the brain where the barrier is not effective, such as the periventricular nucleus), which is synthesized in vivo.

GABA is thought to cause inhibitory effects in the cortex, amygdala, and caudate nucleus. Emitted by Purkinje cell axons, it would lead to inhibition of neurons in the DEITERS nucleus. It acts on the postsynaptic membrane, causing hyperpolarization and an inhibitory potential by increasing Cl^- conductance. It also participates in the inhibitory mechanisms of the spine.

Brain development: In the last two decades, the theory of the excitatory action of GABA in early development is undisputed, based on in vitro experiments on brain slices. The main observations were that, for the hippocampus and neocortex of the mammalian brain, GABA is the first to have excitatory effects and, in fact, is the most important excitatory neurotransmitter in many regions of brain development before the maturation of ergic glutamate synapses [1] [2].

HISTAMINE (imidazolethylamine) is a biogenic amine. It is found in the tissues of animals, plants, bacteria, venoms.

In humans, histamine is found in the lungs, skin, gastrointestinal mucosa.

Histamine metabolism: about 2-3% of endogenous histamine is excreted unchanged in the urine, the rest metabolized to N-methylhistamine and the metabolite 3-methyl imidazole acetate, end product.

Histamine pathways:

- ☐ **A first transformation** takes place in the cytoplasm of the cell periphery, where under the action of histaminase (diamine oxidase) oxidative deamination takes place to form imidazole acetate.
- ☐ **The second transformation** takes place in the brain, where histamine undergoes the action of two enzymes histaminemethyl-transferase and monoamine oxidase B (MAO B); resulting in a 3-methylhistamine intermediate so that the final product is 3-ethyl methyl imidazole.

Digestive effect

Histamine acts as a stimulator of gastric acid secretion, generally adjusting the microcirculation factor. It is used to determine the ability to secrete gastric acid.

Histamine

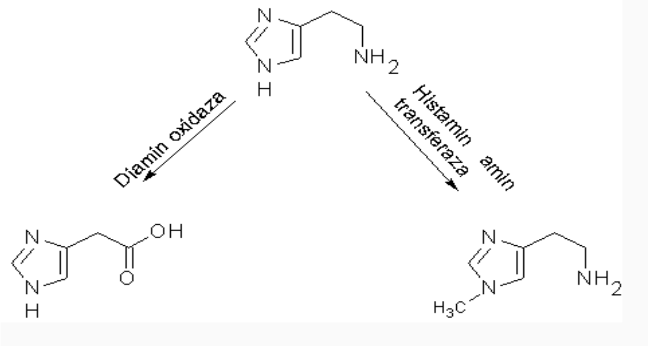
At the skin level : It seems that physical or chemical attacks can cause the release of histamine, which is the main mediator of type I allergy. The clinical manifestations of this type of allergy are:. Urticaria, edema, serous rhinitis, anaphylactic shock. Administered by the vascular intradermal route causes a "triple response" reaction, a red spot appears at the injection site due to dilation of arterioles, which is quickly replaced by a papule with an irregular red areola.

At the level of the circulatory system: At the circulatory level, it is an important mediator. Its effects are proportional to the dose and route of administration: intravenous congestive effect, especially at high doses in the body and head. It lowers blood pressure through vasodilatation and hypovolemia, leading to shock. At the arteriolar level, it causes marked dilation of the terminal post-capillary arterioles and venules.

To the respiratory system : may release mast cells as a result of antigen-antibody interaction having an important role in allergies and may cause allergic bronchoconstriction reactions. Histamines cause weak bronchoconstriction, asthmatics are extremely sensitive to this action.

Chemical synapse – types of chemical mediators:

Receptor	**Action**	**Antagonists**
H1	bronchoconstriction; vasodilatation; increased capillary permeability, itching	Diphenhydramines, Chlorpheniramines, Prometasines, Terphenadines, Astemisol, Loratadins, Cetirizine, Chloropyramine _
H2	Gastric acid secretion, cardiac depressant; esophageal contraction, inhibition of histamine removal from basophils	Ranitidine Phamotidine Nisatidine
H3	Inhibition of synaptic neurotransmission; Setting down histamine synthesis	Thioperamide



About 2-3% of endogenous histamine is excreted in the urine; the rest is metabolized to N-methylhistamine and the metabolite 3-methyl imidazole acetate; final product

CHEMICAL SYNAPSE - TYPES OF CHEMICAL MEDIATORS - SEROTONIN

SEROTONIN is an amine derived from indole. It is found in plant tissues, animal venoms.

Serotonin acts as a neurotransmitter; involved in the production of sleep, mental and emotional processes (depression and anxiety, obsessive-compulsive disorder) motor function in thermoregulation, regulation of blood pressure, in the act of vomiting in hormonal functions.

Examples of serotonin : methysergide, ergotamine, sumatriptan, buspirone, ondansetron.

Serotonin, a neurotransmitter found in various organs, including the central nervous system, plays an important role in the development of depressive and anxiety disorders due to the chemicals they produce .

The chemical formula of raw serotonin is: $HO-C_6H_5-NH-C-(CH_2)_2-NH_2$

Chemical formula: $HO-C_6H_5-NH-C-(CH_2)_2-NH_2$

Natural sources: serotonin is present in various foods (vegetables, potatoes, cereals, etc.)

Biochemical and Physiological Effects of Serotonin: Neurons interact with each other through chemicals called neurotransmitters. Other disorders are caused by either underproduction or overproduction of neurotransmitters, or by the fact that the neurons do not have enough receptors for the neurotransmitters.

Researchers say that people with OCD have an imbalance of serotonin.

The serotonin content in the blood of obsessive-compulsives and lovers is 40% lower than that of normal subjects.

Antidepressants generally act on serotonin, a neurotransmitter.

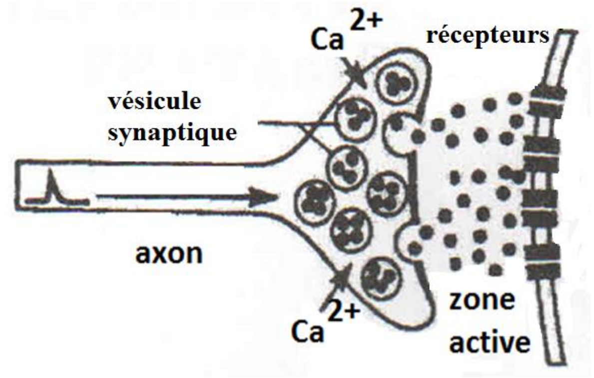
However, **depression is thought to be caused by a lack of serotonin receptors.** The latest research on the mental illness schizophrenia shows that excess serotonin in the body may be the cause and precursor to this and other mental illnesses.

Maintaining an adequate level of serotonin in the human body varies from organism to organism due to diet, lifestyle, etc.

THE SYNAPTIC CHEMICAL TRANSMISSION MECHANISM

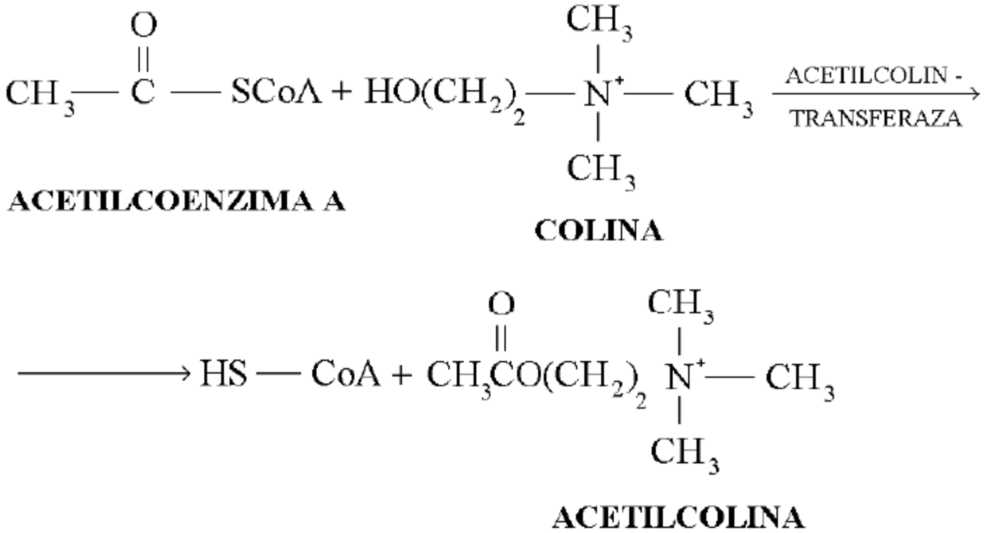
This involves several steps:

1. Synthesis and storage of the chemical mediator
2. Chemical release of mediators into the synaptic cleft
3. Mediator diffusion in the synaptic cleft
4. The response to foci in the post-synaptic membrane
5. Inactivation of the chemical mediator



Stages of chemical transmission

- Mediator synthesis and storage



$$CH_3-\overset{\overset{O}{\|}}{C}-SCoA + HO(CH_2)_2-\underset{CH_3}{\overset{CH_3}{N^+}}-CH_3 \xrightarrow[\text{TRANSFERAZA}]{\text{ACETILCOLIN -}}$$

$$\longrightarrow HS-CoA + CH_3\overset{\overset{O}{\|}}{C}O(CH_2)_2\underset{CH_3}{\overset{CH_3}{N^+}}-CH_3$$

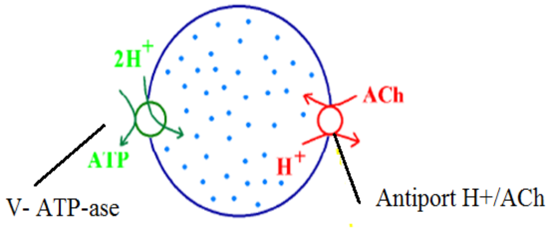
http://web.williams.edu/imput/synapse/pages/IA3.html

SUMMARY AND STORAGE of chemical mediators:

Acetylcholine (Ach) is synthesized by the presynaptic side, resulting from the hillock acetylation reaction.

The chemical reaction catalyzed by the enzyme acetylcholinesterase:

After synthesis, ACh molecules are packed into vesicles of 4000 to 10000 mediator molecules/vesicle.



Each mediating vesicle, approximately 500 Å in diameter, contains 4,000 to 10,000 Ach molecules. The storage mechanism involves the combined action of the two active transport mechanisms:

- A vacuolar-type ATPase with the role of generating a proton gradient between the cytoplasm and within the bladder - and
- secondary active transport of an antiporter type of Ach/H $^{+}$ that uses the aforementioned proton gradient to drive endergonic mediator molecules into the vesicle.

RELEASE OF THE CHEMICAL MEDIATOR BY THE SYNAPTIC CLEFT

The presynaptic membrane contains, in addition to the voltage-gated ion channels required for the generation and propagation of action potentials, voltage-gated Ca^{2+} ion channels. Action potentials propagated across the presynaptic membrane trigger its depolarization

In resting cells, **the intracellular concentration is** $[Ca^{2+}]_i < 10^{-7}$ **M**, it is much lower than the **extracellular concentration** $[Ca^{2+}]_e = 1.5$ **mM .**

Depolarization of the presynaptic membrane will cause these channels to open, followed by a strong influx of Ca ions.

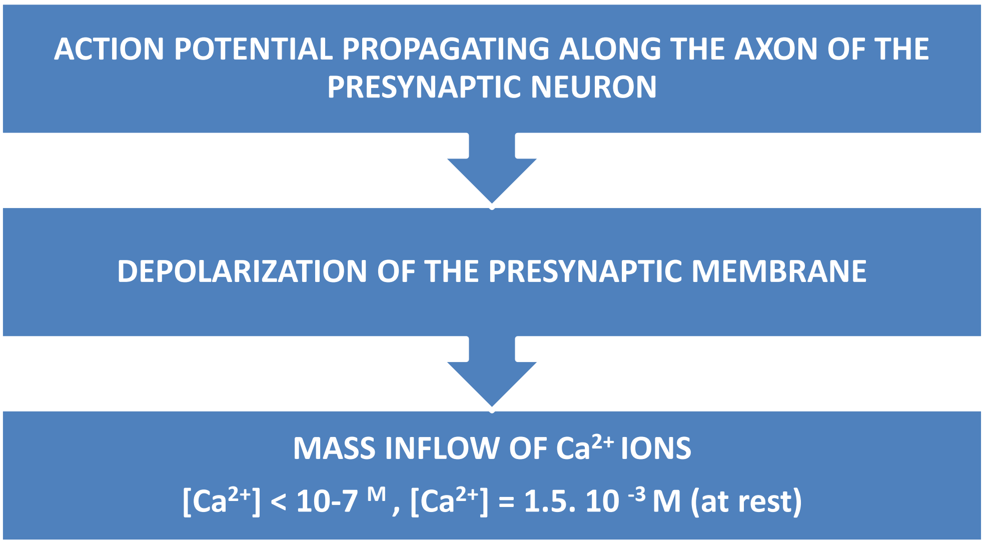
In the vicinity of the presynaptic membranes there are mediator vesicles of high density, being grouped by means of an intracellular protein called pyruvic synapsin.

The increase in the intracellular calcium concentration results in the phosphorylation of synapsin, followed by the separation of the vesicles from the group.

Being in close proximity to the presynaptic membrane, under the action of an anchor protein complex whose activity depends on the presence of Ca^{2+}, the vesicles fuse with the presynaptic membrane passing through the process of exocytosis by spilling their contents into the synaptic cleft.

The mechanism is known as the **QUANTUM THEORY OF SYNAPTIC TRANSMISSION** because by exocytosis at each vesicle a packet of several thousand ACh molecules called quanta is released into a synaptic cleft.

RELEASE OF MEDIATORS



DIFFUSION OF THE MEDIATOR THROUGH THE SYNAPTIC CLEFT

Unlike the electrical synapse, the chemical synapse induces a delay of about 500 µs between the moment when the action potential reaches the level of the presynaptic membrane, triggers the depolarization of the presynaptic membrane and the moment of its response at the level of the postsynaptic membrane.

The duration of diffusion of ACh molecules through the synaptic cleft contributes to the delay, but the time required for these molecules to move through the space separating the pre- and postsynaptic membranes, calculated on the basis of the Einstein-Smoluchowschi equation, does not exceed 2-5 µs.

The main reasons for the delay are generated on the one hand by the processes taking place in the presynaptic membrane (slow opening of Ca channels, on the other hand by synapsin phosphorylation, exocytosis of mediator vesicles).

What happens in the postsynaptic membrane.

Once they reach the postsynaptic membrane, Ach molecules undergo a process of lateral diffusion to find vacant sites in the composition of specific mediator receptors.

Triggering the response at the level of the POST-SYNAPTIC MEMBRANE

The first step in the generation of the postsynaptic potential consists in the binding of mediator molecules to specific receptors located in the postsynaptic membrane. Ach-activated ion channels with a pentametric structure each have two neurotransmitter binding sites:

This is a non-selective cation channel:

- It presents a high ionic conductance value; approx. 27pS and opens upon binding the two mediator molecules:

- As a result of the binding of the mediator, the ion channel opens, producing ion flows that cause changes in the postsynaptic membrane potential:

Triggering the response at the QU level of the POST-SYNAPTIC MEMBRANE

Depending on the nature of the changes, synapses are classified as follows:

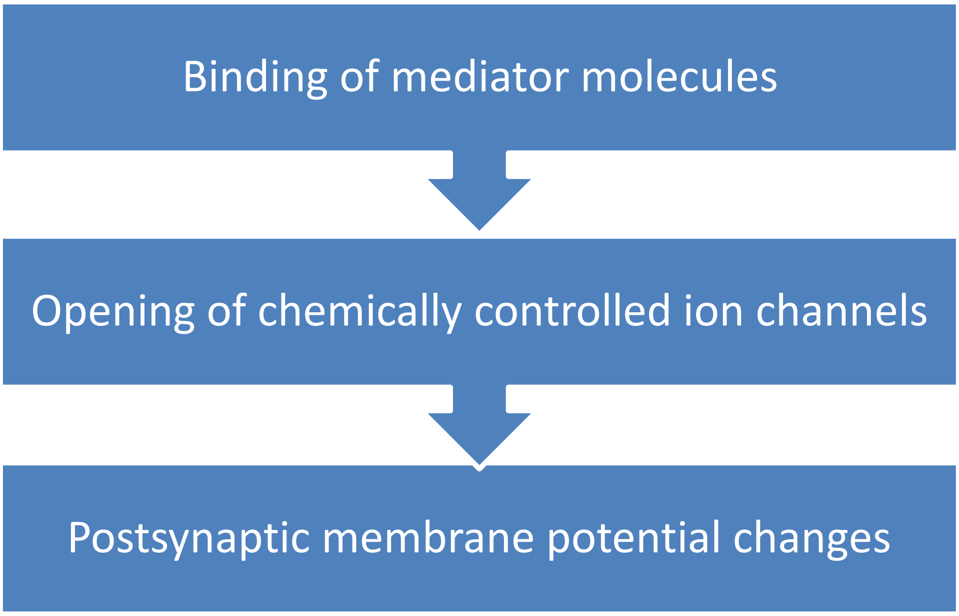
1. Excitatory synapse: where the flow of Na^+ and K^+ ions causes the depolarization of the postsynaptic membrane and the increase in the excitability of the postsynaptic cell.

The mediators, which generate the depolarization of the postsynaptic membrane and are: acetylcholine and glutamate.

2. **Inhibitory synapse**:: this is the case where Cl^- ions cause hyperpolarization of the postsynaptic membrane, with a decrease in the excitability of the postsynaptic cell.

The mediators that generate depolarization of the postsynaptic membrane are glycine and gamma aminobutyric acid (GABA).

TRIGGER THE POST-SYNAPTIC RESPONSE



Inactivation of chemical mediators

ACh molecules that have remained free in the synaptic cleft are hydrolyzed by an enzyme called: acetylcholinesterase into choline and acetate ions.

The choline resulting from the hydrolysis reaction is transported back to the presynaptic side by Na^+ symport/choline: using the free energy resulting from the passive transport of Na^+ ions from the synaptic cleft inside the presynaptic cell, choline molecules are actively transported in the same manner, being reintroduced into the presynaptic termination button.

inactivation of the chemical mediator

ACH hydrolyse

$$\text{Acetylcholine} \quad \overset{\text{acetylcholine}}{\underset{\text{esterase}}{\Rightarrow}} \quad \text{choline}$$

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