МЕДИЦИНСКИ ФАКУЛТЕТ
УНИВЕРЗИТЕТ У КРАГУЈЕВЦУ

THE MEDICAL FACULTY
UNIVERSITY OF KRAGUJEVAC

Integrated Academic Studies of Medicine

2023/2024.

MEDICAL CHEMISTRY

I lesson

Prof. Dr. Nedeljko Manojlovic

- **Course unit contents**

- Introduction to Medical chemistry; WHAT MEDICINAL CHEMISTRY TEACHES?
- The importance of chemistry as a science;
- General chemistry; Basic chemical terms, chemical laws, chemical bonds, intermolecular interactions, types of chemical compounds,
- Water, solutions, chemical analysis, kinetics and equilibrium, acidity of solutions, pH value and pH of body fluids, redox reactions;

- Inorganic chemistry and chemistry of bioelements - properties of elements of the main groups of the periodic system of elements; Inorganic compounds; Acids, bases and salts; Salt hydrolysis;

- Chemical reactions; Types of chemical reactions;
- Dispersion systems; Solubility; Concentration of the solution; Electrolytes;
- Diffusion; Dialysis; Osmosis; Buffers; Biologically important buffers; Biogenic elements, macro and microelements,
- Organic chemistry: functional groups, chemical reactions of organic molecules in biological systems and their role, organic compounds, aliphatic and aromatic organic compounds,
- Carbonyl group, aldehydes, ketones, properties and reactivity in biological systems;
- Heterocyclic compounds as components of important biomolecules;

- Organic compounds with nitrogen and organic compounds with sulfur,
- Primary biomolecules and their role and importance; Amino acids,
- Peptides,
- Proteins, structure, division and their role and importance;
- Carbohydrates, monosaccharides, disaccharides and polysaccharides and their role and importance;
- Lipids, division of lipids, fatty acids, glycerides, sterols, phospholipids;
- Secondary biomolecules and their importance; Alkaloids
- Instrumental methods in medicine, gas chromatography, liquid chromatography (HPLC), spectroscopic methods.

- **Literature**

- Kaim W, Schwederski B, Klein A. Bioinorganic Chemistry: Inorganic elements in the Chemistry of Life: An Introduction and Guide. Chichester, West Sussex, United Kingdom: Wiley; 2006.

- McMurry JE, Ballantine DS, Hoeger CA, Peterson VE. Fundamentals of General, Organic, and Biological Chemistry. 7th edition. Boston: Pearson; 2012.

Number of active teaching classes: 45	**Lectures:** 30	**Practice:** 15

Exam prerequisites	No. of points:	Final exam	No. of points:
student's activity during lectures		written exam	
practical classes	10*	practical exam	
colloquiums	20**	oral exam	70

* 2 questions will be answered in the last (5th) week of classes.

** the colloquium will be held after the lectures and exercises, until the end of the semester.

Everything that surrounds us is composed of chemical elements and compounds.

1\. МЕДИЦИНСКИ ФАКУЛТЕТ УНИВЕРЗИТЕТ У КРАГУЈЕВЦУ THE MEDICAL FACULTY UNIVERSITY OF KRAGUJEVAC

THE IMPORTANCE OF CHEMISTRY AS A NATURAL SCIENCE

- The human body consists of chemical compounds:

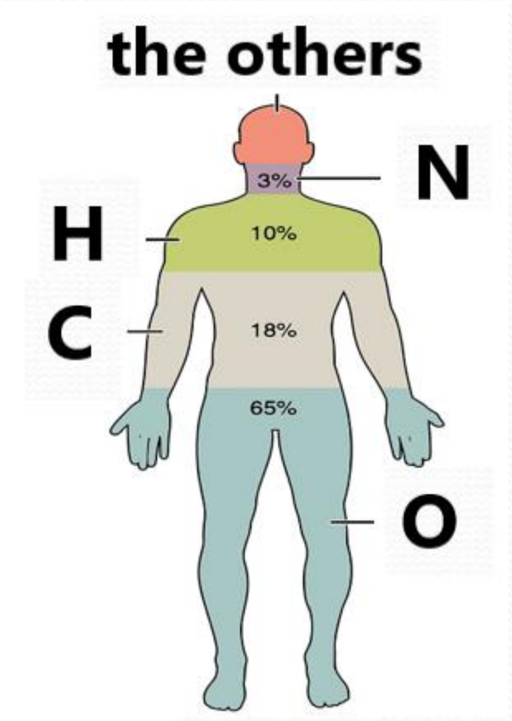
mostly water, followed by carbohydrates, lipids, proteins and others.

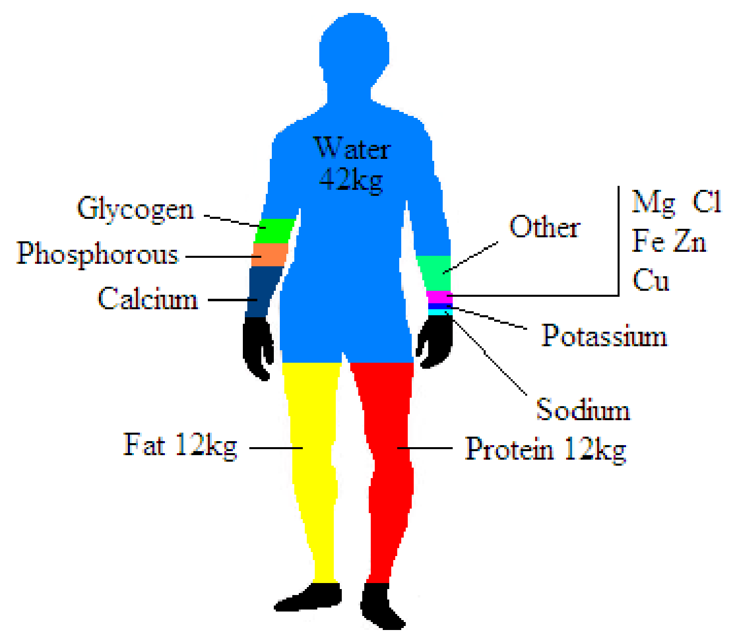
Almost 99% of the human body consists of 6 elements:

carbon, hydrogen, nitrogen, calcium and phosphoru

Of the remaining one of about 0.85% makes up only 5 elements –

potassium, sulphur, sodium, chlorine and magnesium.

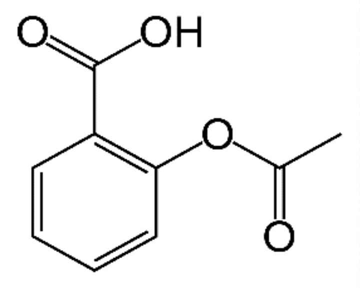




- **Food** consists of organic and inorganic compounds
- **Medicines** consist of natural and synthetic chemical compounds.

vegetables

aspirine



- **The Sun** consists mostly of hydrogen (about 74% of its mass or 92% of its volume), then helium (about 24% of its mass and 7% of its volume) and small amounts of other elements
- **Earth** is mostly composed of iron (32.1%), oxygen (30.1%), silicon (15.1%), magnesium (13.9%), sulfur (2.9%), nickel (1. 8%), calcium (1.5%) and aluminum (1.4%).

Basic chemical terms

Chemistry has been defined as the study of matter and its interconversions.

What does CHEMISTRY study?

The composition and properties of matter, as well as the phenomena that occur when different substances react with each other.

Matter - everything that surrounds us; it cannot be destroyed or created, but only pass from one form to another.

Matter consists of objects, living beings, natural objects and phenomena.

MATTER

SUBSTANCES

- It has mass
- Takes up space
- Certain composition
- Characteristic features
- Builds physical bodies

PHYSICAL FIELD

- GRAVITY
- ELECTROMAGNETIC
- NUCLEAR

SUBJECT OF STUDY OF CHEMISTRY

SUBSTANCES, THEIR STRUCTURE AND PROPERTIES, THE CHANGES TO WHICH THEY ARE SUBJECTED AND THE LAWS UNDER WHICH THE CHANGES TAKE PLACE

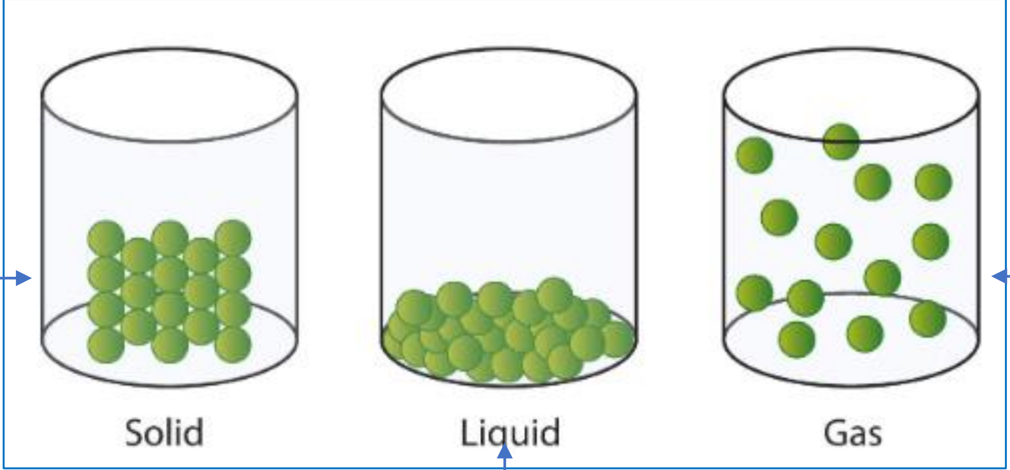
three common states of matter:

solid *the form of matter characterized by rigidity;* a solid is relatively incompressible and has fixed shape and volume.

liquid *the form of matter that is a relatively incompressible fluid;* a liquid has a fixed volume but no fixed shape.

gas *the form of matter that is an easily compressible fluid;* a given quantity of gas will fit into a container of almost any size and shape.

fixed shape and volume



no fixed shape and no fixed volume

no fixed shape and fixed volume

Properties of substances

- **Physical properties**: are **without changing** the chemical composition of the substance.
- **Chemical properties**: show how a substance is **transformed** into another substance

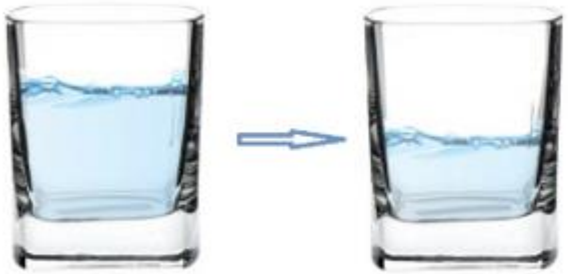
Changes in substances

- **Physical changes**
  - ➢ The substance **does not change** its chemical composition
  - ➢ Accompanied by a change in energy
- **Chemical changes**
  - ➢ The substance **changes** its chemical composition
  - ➢ Accompanied by a greater energy change than a physical change

Physical changes

CHANGE IN THE STATES OF AGREGATION

DISSOLUTION



melting ice

water evaporation

Chemical changes = Chemical reactions

RUSTING
рђање

BURNING

rotting of an apple

burning a match

building patina on the roofs

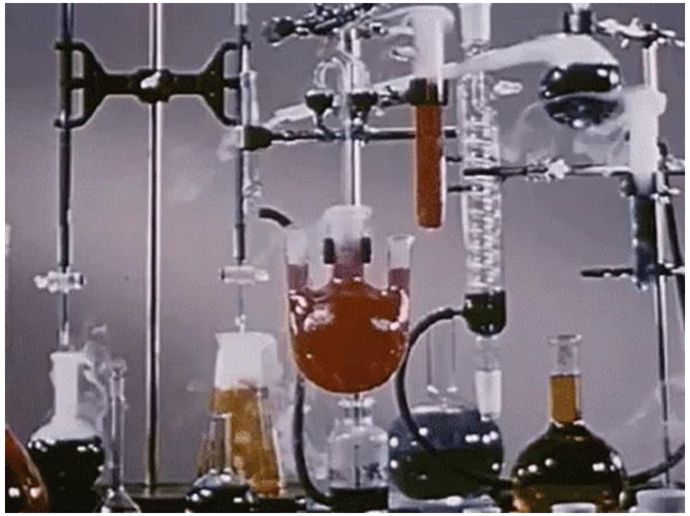
SUBSTANCES

Substances can be divided into pure substances and mixtures.

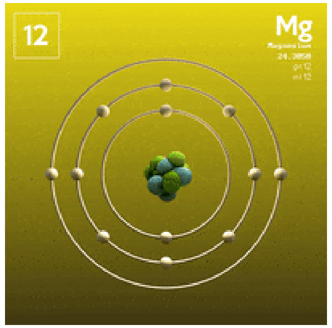
Pure substances

Mixture

- Permanent composition
- Defined physical and chemical properties
- They do not contain admixtures of other substances
- Homogeneous substances (same composition and properties in all parts)
- They can be simple and complex



PURE SUBSTANCES



Elementary substances (Elements)

- **Pure substances** that cannot be decomposed into simpler substances by chemical methods (by heat, electric current, chemical reactions).
- An element is a substance that consists of only one type or kind of atom.
- All elements are mostly pure substances:
- oxygen, nitrogen, hydrogen, sulphur, tin, platinum, gold, silver, mercury, iron and others.

Compounds

- **Complex pure substances** consisting of two or more elements
- They can be broken down into simpler substances using the usual methods (by heat, electric current, chemical reactions): other compounds and/or elementary substances (chemical analysis)
- Homogeneous substances - have the same composition and properties in all their parts
- water, salt or crystals, baking soda and others.

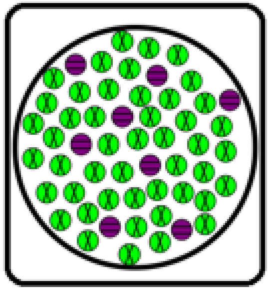
SUBSTANCES

Pure substances

Mixtures

- They contain two or more pure substances
- They do not have exactly defined properties (they depend on the ingredients that make up the mixture)

Homogeneous



have the same composition and properties in all their parts

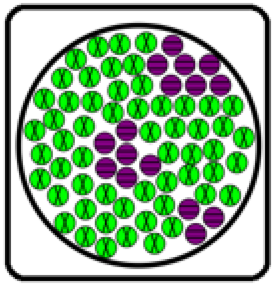
- The ingredients of the mixture cannot be seen with the naked eye or with an ordinary microscope
- Particle size < 1.0 nm

Vinegar is a homogeneous mixture

Heterogeneous

do not have the same composition and properties in all their parts

- The ingredients of the mixture can be seen with the naked eye or with a microscope



Milk and mayonnaise are heterogeneous mixtures

Pure substances retain their properties in mixtures

Mixtures can be separated into components

Chromatographic methods

Thin layer chromatography TLC

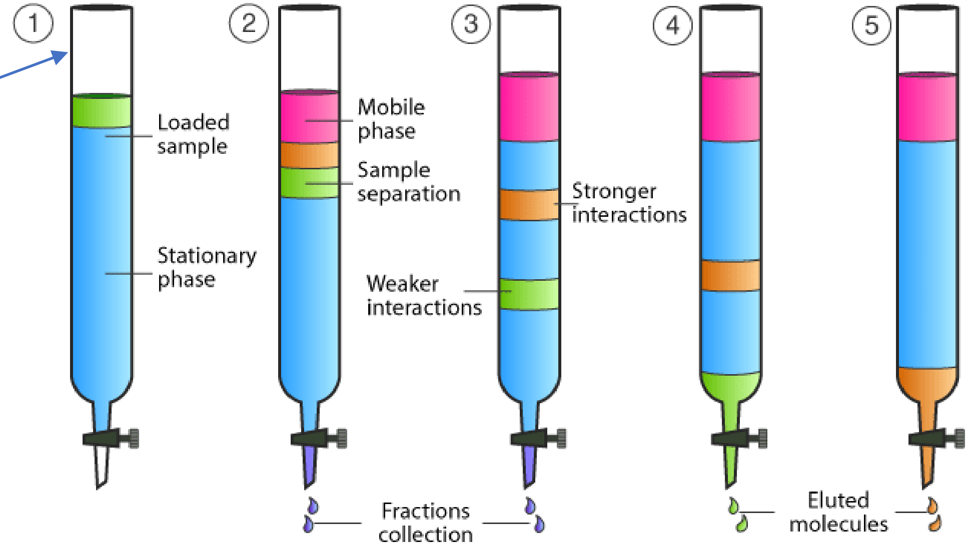
Separation of chemical compounds

Chemical compounds

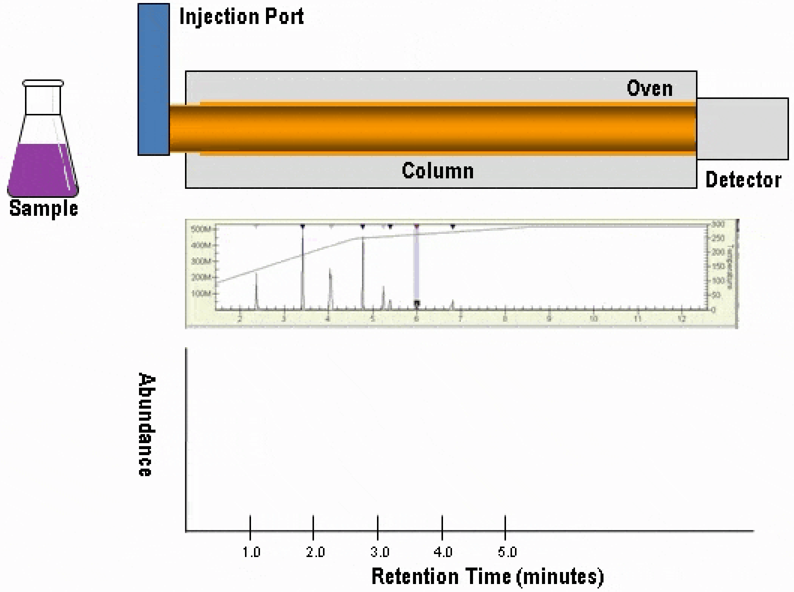
Mobile phase solvents

Column chromatography

glass column



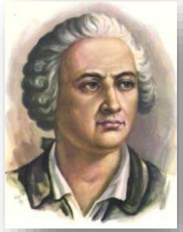
Gas chromatography



Chromatogram

HPLC chromatography

Lomonosov
1756.



LAW OF CONSERVATION OF MASS

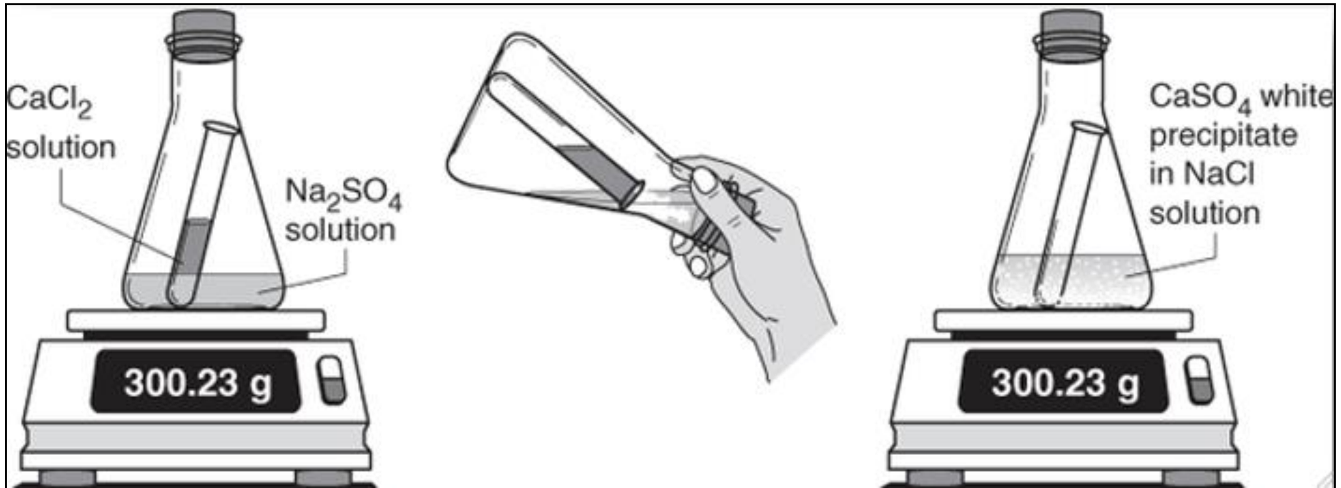
Lavoisier
1774.

The total mass remains constant during a chemical change (chemical reaction).

$2H_2 + O_2 \rightarrow 2H_2O$
2 g + 16 g = 18 g
18 g = 18 g

$M_{p1} + M_{p2} = M_{п1} + M_{п2}$
m(reactants) = m(products)

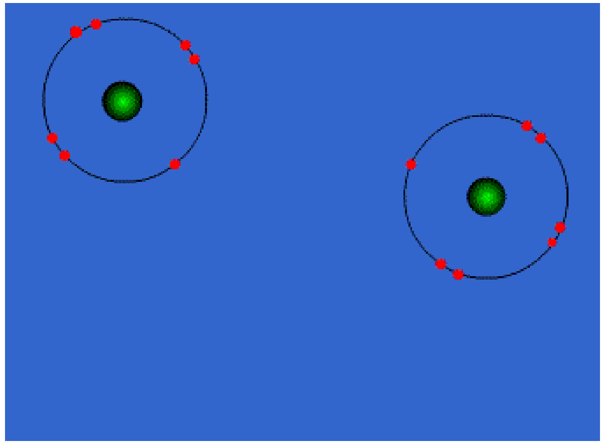
$CaCl_2 + Na_2SO_4 = CaSO_4 + 2NaCl$



CHEMICAL BOND

Chemical bond represents the tendency of elements to achieve a stable electronic configuration of the nearest noble gas (octet rule).

When atoms are combined into larger units - molecules or crystals, they bond with each other, and the force that holds them together is called a **CHEMICAL BOND**

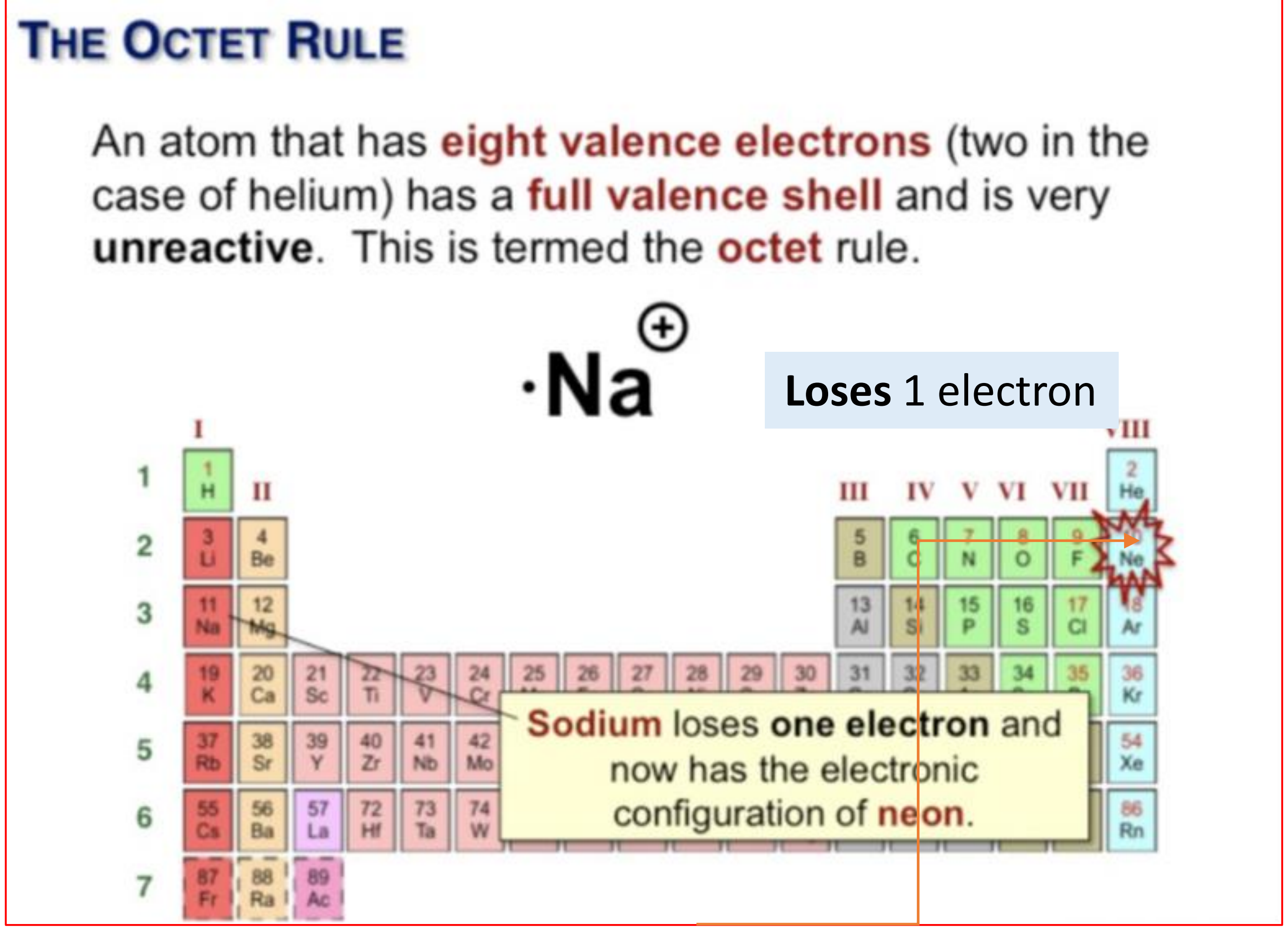


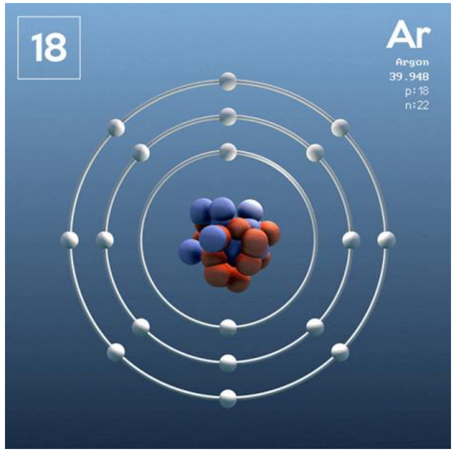
By combining atoms into larger units, the energy of the system is lowered.

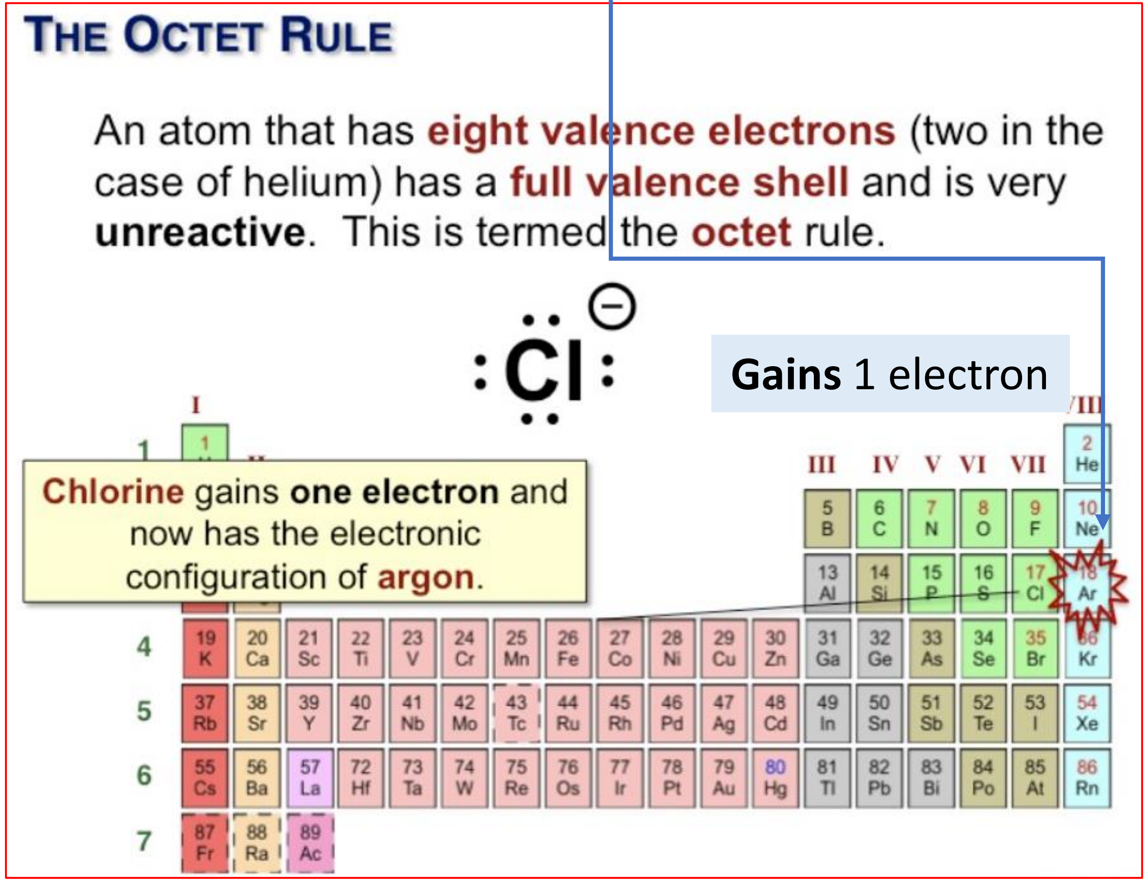
The building of a chemical bond can be explained by the electronic theory of valence.

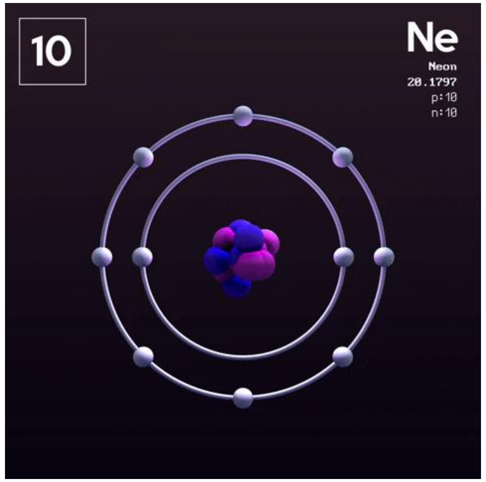
There are two basic types of chemical bonds:

ionic and covalent.









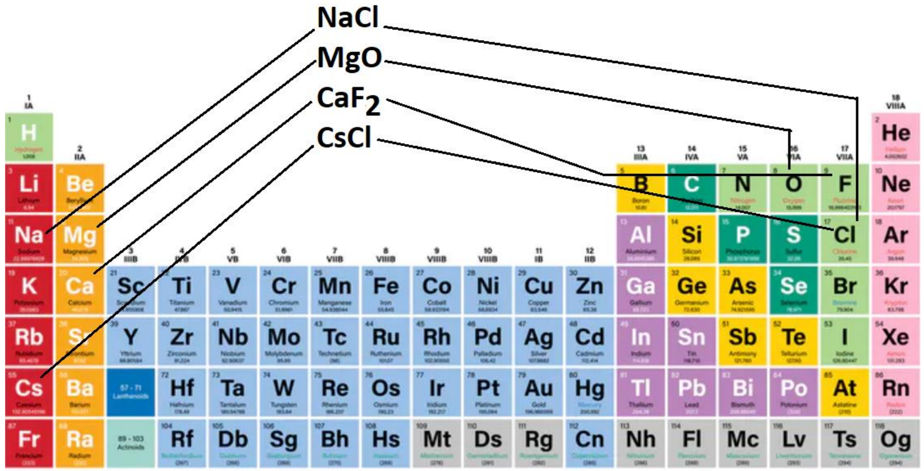
full valence shell

IONIC BOND

An ionic bond is formed by the complete transfer of electrons from one atom to another, which creates oppositely charged ions that attract each other.

The atom that released an electron becomes a positively charged ion, a cation, and the atom that received a negative charge becomes an anion.

Ionic bond - it is formed by elements that have low values for ionization energy (metals) and elements that have high electron affinity (non-metals).



Typical ionic compounds are halides and oxides of alkali and alkaline earth metals

LiF, KCl, NaI, K_2O, CaO...

By exchanging electrons, atoms of metals and non-metals achieve stable electronic configurations (doublet or octet).

An attractive electrostatic force acts between the formed ions

Formation of an ionic bond on the example of sodium chloride. Z(Na) = 11, Z(Cl) = 17

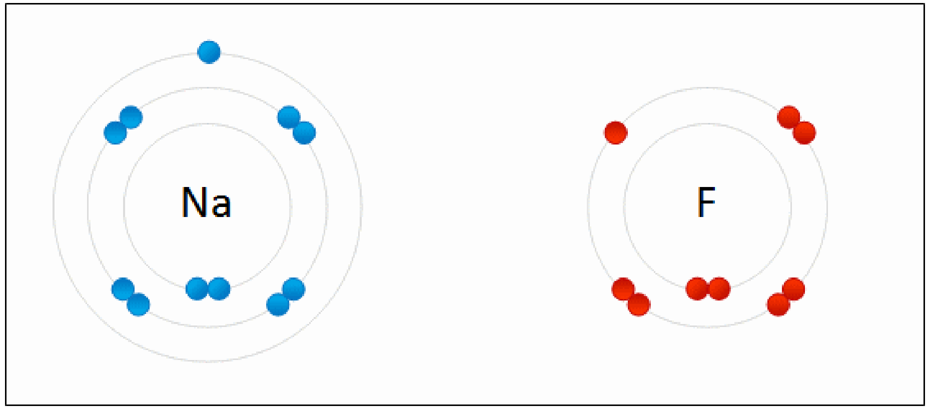
Valence electron

$_{11}Na\ 1s^2\ 2s^2 2p^6 3s^1 \longrightarrow Na^+\ 1s^2\ 2s^2 2p^6 + e^-$

$1s^2\ 2s^2 2p^6$ = $_{10}Ne$

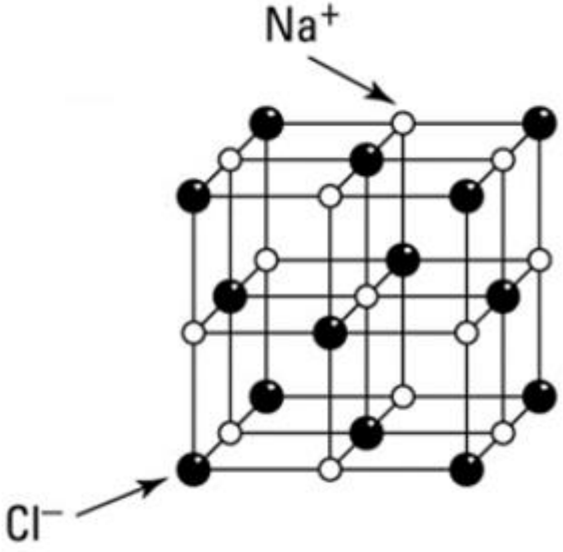
$_{17}Cl\ 1s^2 2s^2 2p^6 3s^2 3p^5 + e^- \longrightarrow Cl^-\ 1s^2 2s^2 2p^6 3s^2 3p^6$

$1s^2 2s^2 2p^6 3s^2 3p^6$ = $_{18}Ar$



Na^+ Cl^-

Attractive electrostatic forces → **Ionic bond (heteropolar bond)**

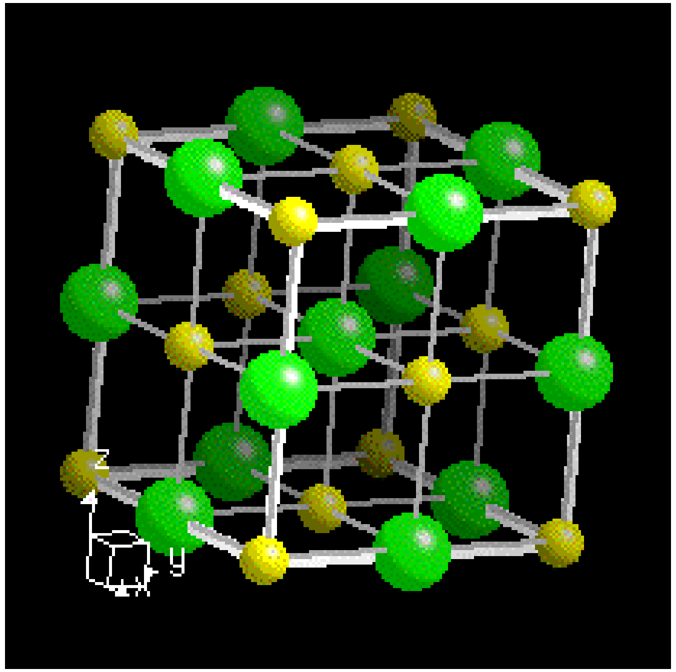


Na· + ·Cl: ⟶ [Na· ·Cl:] ⟶ [Na⁺ :Cl:⁻]

atoms | **electron donor** (Na) | **electron acceptor** (Cl) | **ion pair**

IONIC COMPOUNDS

- They contain **positive and negative ions**, regularly distributed in the crystal lattice.
- **Ionic compounds** are characterized by high boiling points.
- They are created mostly in polar solvents, and their aqueous solutions also conduct electricity.



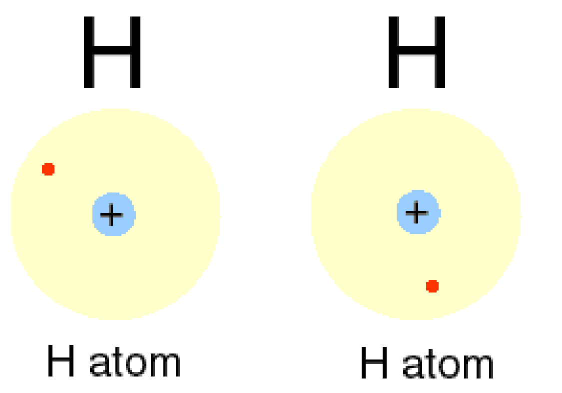
crystal lattice of sodium chloride

There are no ion pairs in the NaCl crystal, but each Na+ ion is surrounded by six Cl- ions and vice versa

COVALENT BOND

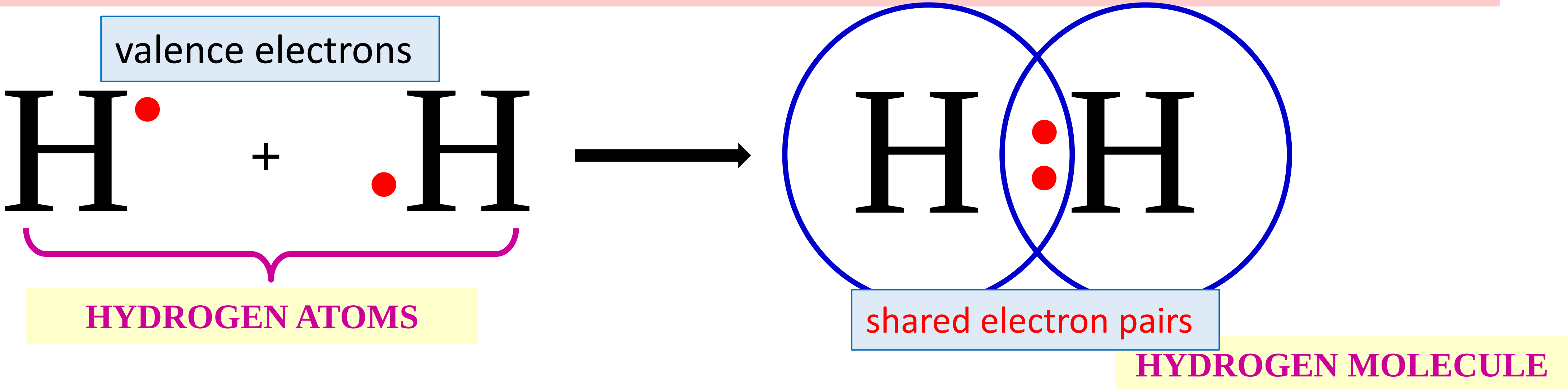
Covalent bond is formed by the creation of shared electron pairs between non-metal atoms.

It can be polar, non-polar and coordinate, which depends on the nature of the atoms entering into the chemical bond.

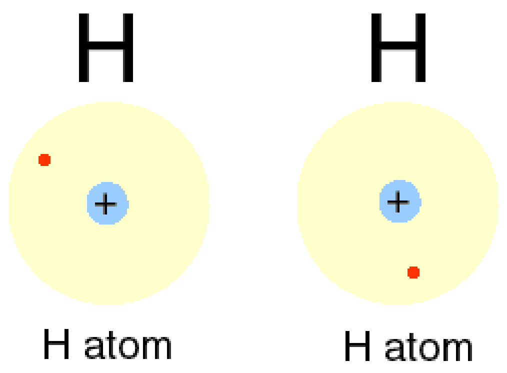


Covalent bond - a consequence of the tendency of atoms of an element to achieve a stable electronic configuration of a noble gas.

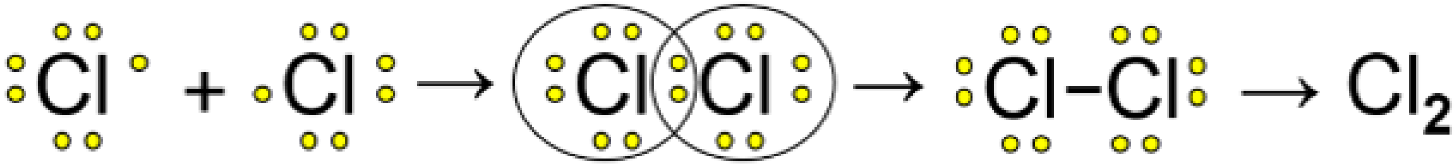
A covalent bond is formed by combining the valence electrons of atoms of the same or different elements, whereby common electron pairs are formed.



single bond



non-polar covalent bond

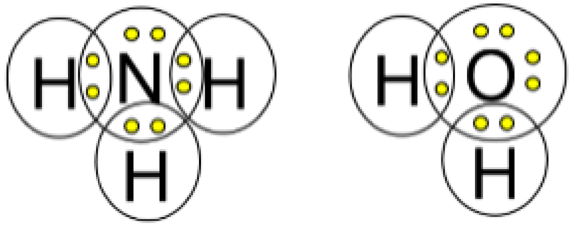


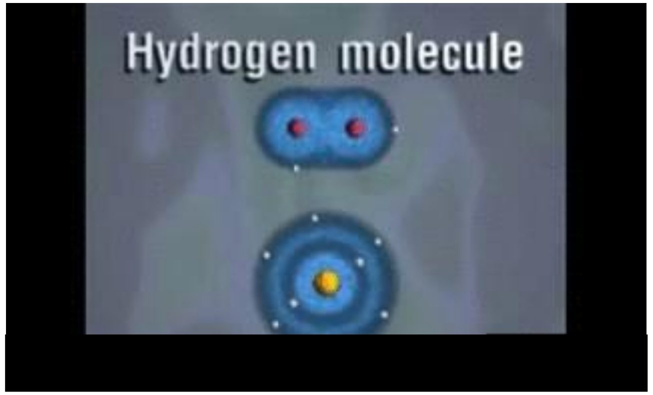
Forming a chemical bond of a chlorine molecule. Z(Cl) = 17

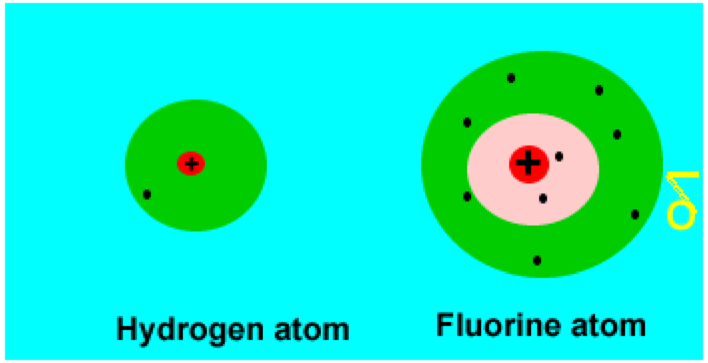
The resulting **shared ONE electron pair** represents a **single covalent bond**.

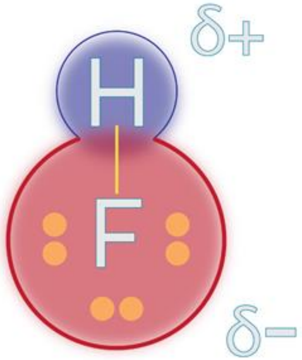
A shared electron pair can be represented by a line in Lewis structural formulas.

Polar covalent bond (H_2O, NH_3, HF, HCl, HBr …)

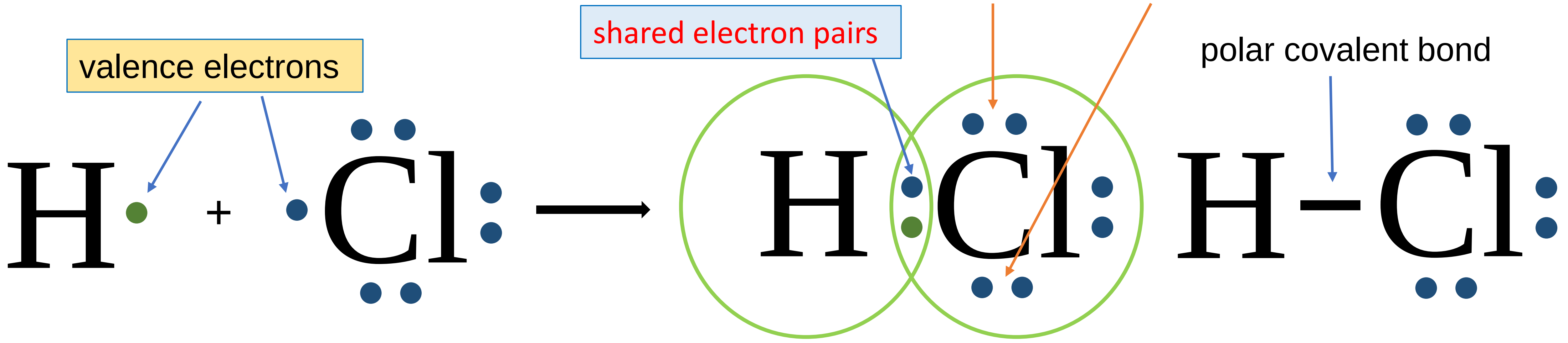




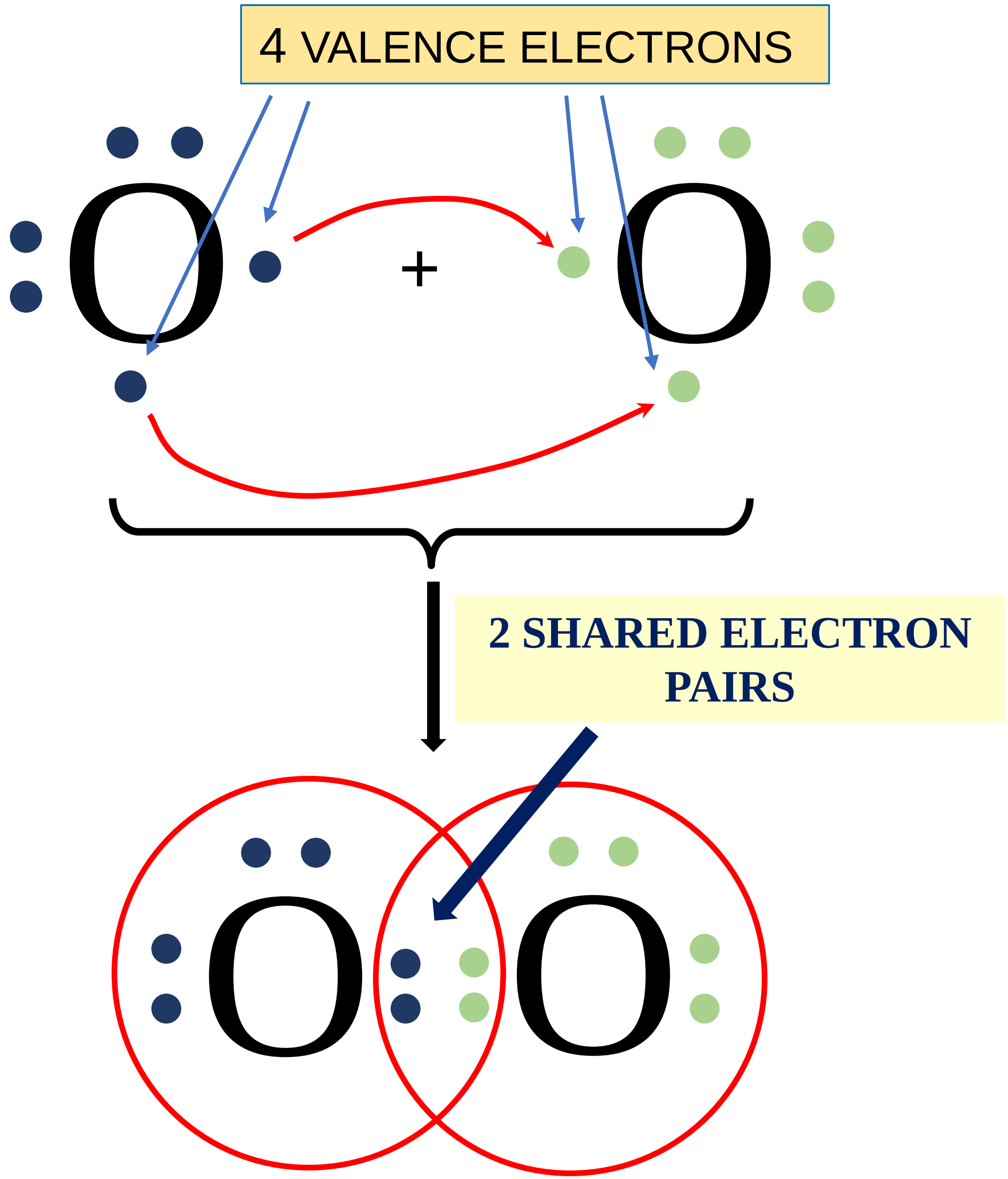




Electrons that do not participate in a chemical bond - free electron pairs.

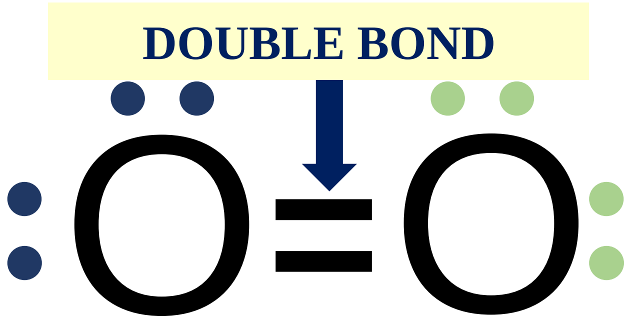


Double bond



Covalent bond length and strength

Molecule	Chemical bond length (pm)	Chemical bond energy (kJ/mol)
F—F	143	159
O=O	121	498
N≡N	110	946

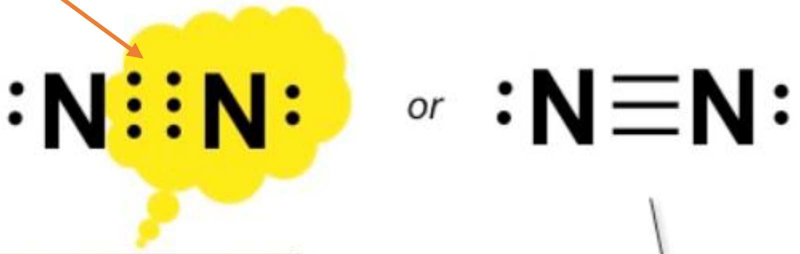


the oxygen molecule has the formula O_2

Lewis structure for **molecular nitrogen** (N_2).

3 SHARED ELECTRON PAIRS

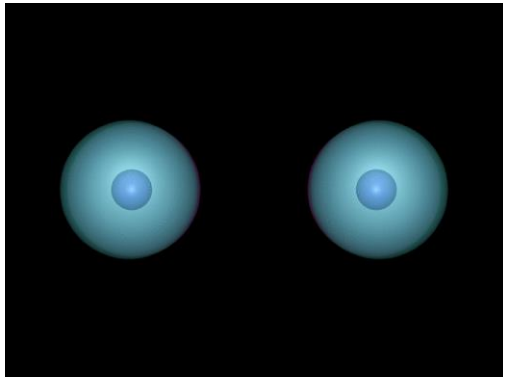
4 VALENCE ELECTRONS



Note that each nitrogen atom has eight valence electrons, including the shared pairs.

8

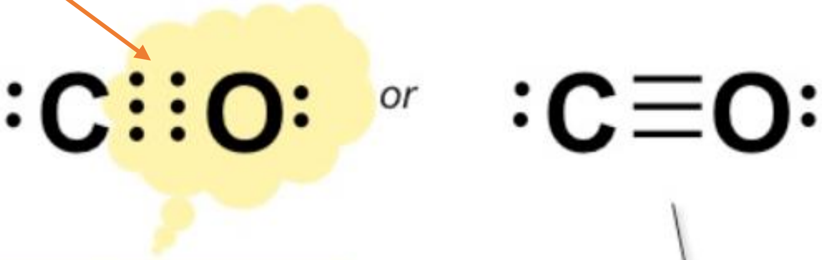
TRIPLE BOND



Lewis structure for carbon monoxide (CO).

2 SHARED ELECTRON PAIRS

4 VALENCE ELECTRONS



Note that each atom has eight valence electrons, including the shared pairs.

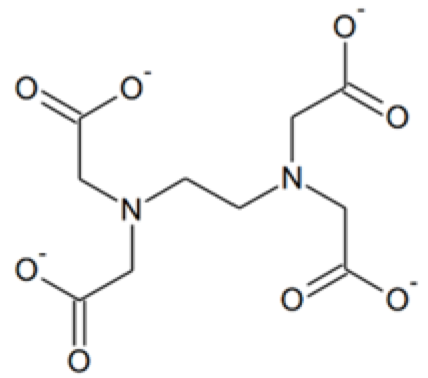
8

TRIPLE BOND

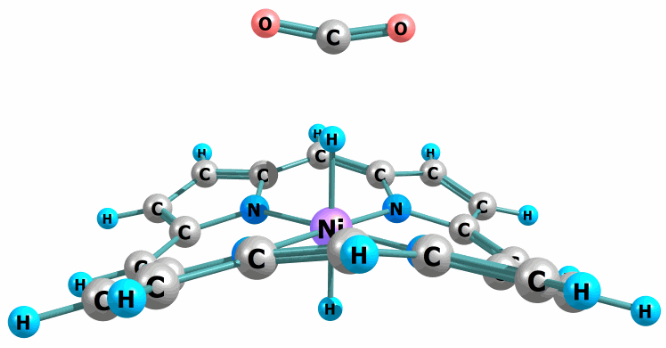
COMPLEX COMPOUNDS

A coordinate (dative) bond occurs when an electron pair is provided by only one atom (donor), while the other atom is called an acceptor (SO_2, SO_3, NO, etc.).

Cisplatin (cisplatinum), is one of the most important anticancer agents used in medicine.



Ethylenediaminetetraacetic acid (EDTA)
edetic acid



Complex compound

Heme, the component of hemoglobin that transports oxygen in the blood, is a complex (chelate) of porphyrin and iron ions.

hemoglobin

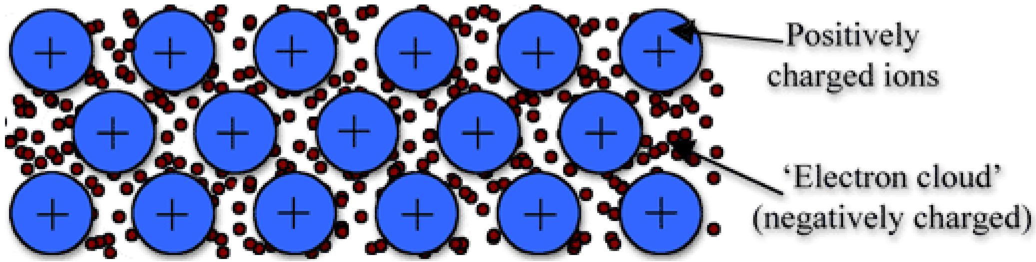
Chlorophyll is a complex of porphyrin and magnesium ions.

Cyanocobalamin (vitamin B12) is a complex of cyanide ligand ions and cobalt (III).

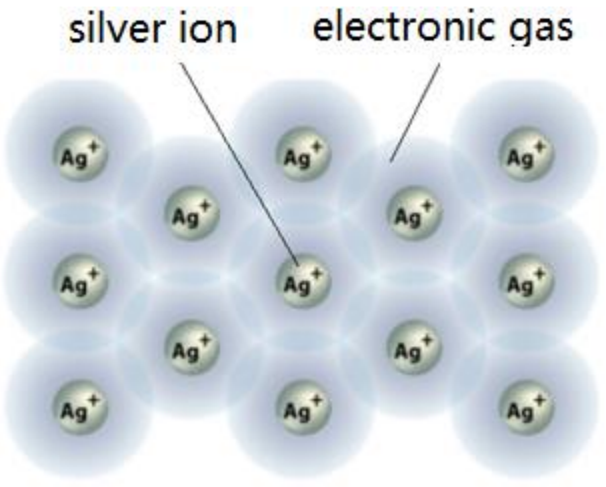
METALLIC BOND

Metals have a solid aggregate state and have a metallic luster.

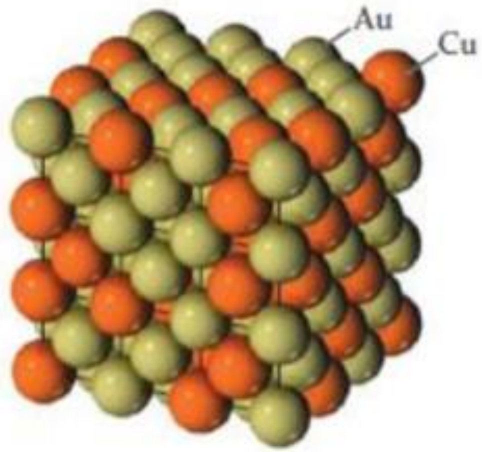
The **silver** crystal lattice consists of silver ions and delocalized electrons (electron cloud).



metal bond in gold



metallic Bond in silver



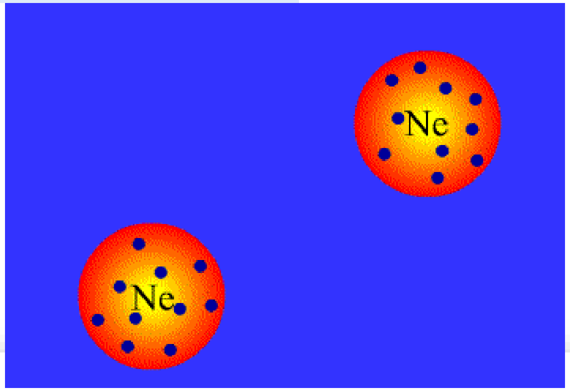
Tutankhamun's golden mask weighs 24 kilograms.

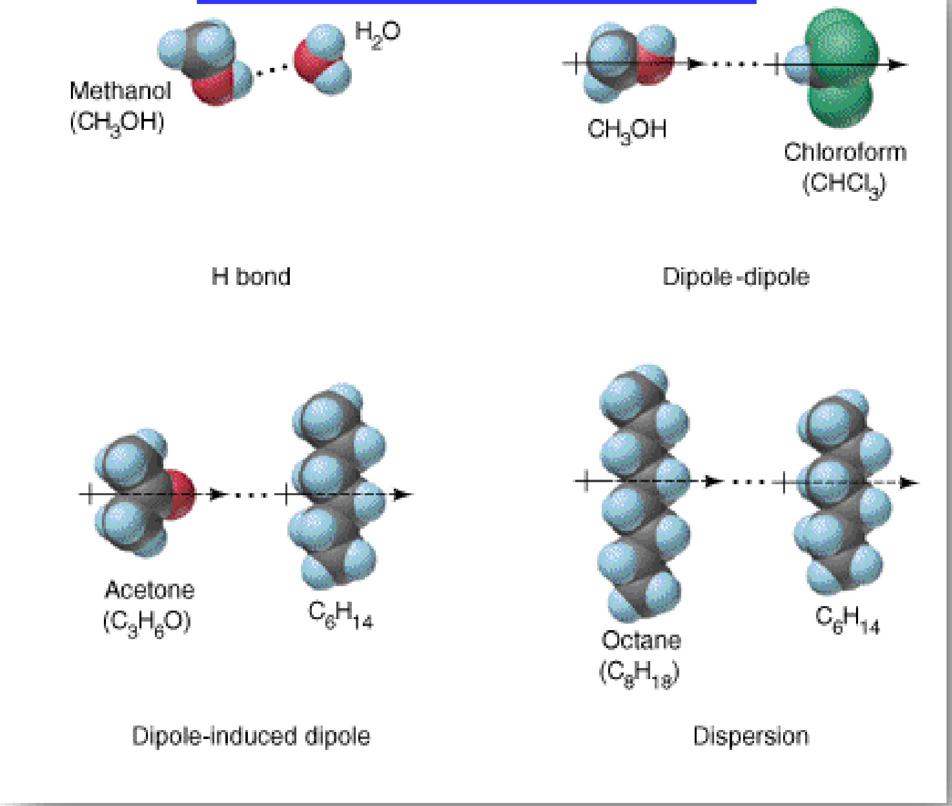
14-karat gold contains 14 parts gold to 24 parts alloy, while 18-karat gold alloy contains 75% of gold.
The heaviest gold bar on Earth has a mass of 250 kg. The maximum purity of gold can be 24-karat alloy.

Intermolecular (Van der Waals) interactions

Intermolecular interactions that exist between uncharged molecules are:

1. Ion-dipole and dipole-dipole interactions
2. London dispersion forces (interactions)
3. Hydrogen bond



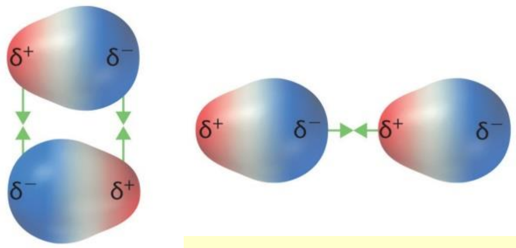


These interactions determine the physical properties of a substance:

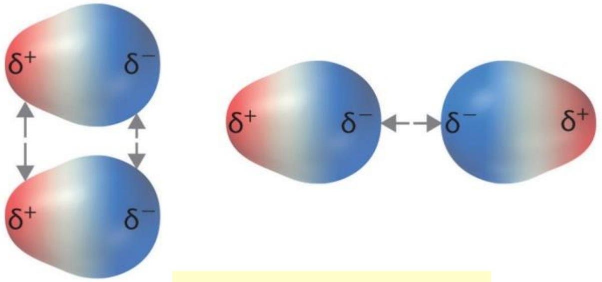
Melting point
Boiling point
Physical state
Viscosity
Surface tension of liquid

Dipole-dipole interactions

Interactions between polar molecules



attractive forces



repulsive forces

$$\overset{\delta+}{H} - \overset{\delta-}{Cl} \cdots\cdots \overset{\delta+}{H} - \overset{\delta-}{Cl}$$

Dipole-dipole interactions

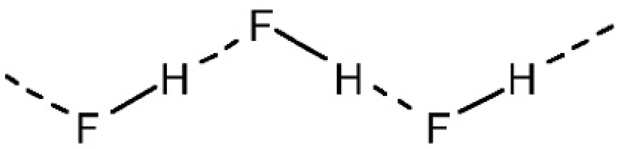
The energy of the dipole-dipole interaction depends on the size of the dipole moment of the molecule, but they are **up to 100 times weaker** than the covalent bond.

Dipole-dipole interaction energy: 1 – 10 kJ/mol

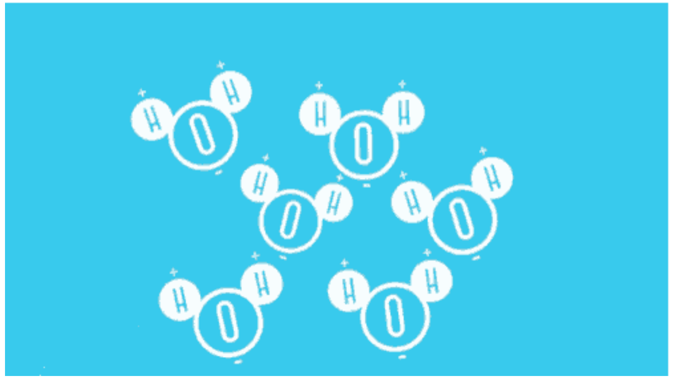
HYDROGEN BOND

The hydrogen bond represents the strongest intermolecular interaction.
It is formed by connecting a hydrogen atom of one molecule with an atom of high electronegativity of another molecule, such as fluorine, oxygen or nitrogen (H-F, H-O, H-N).

Hydrogen bond is an interaction between three atoms.



Hydrogen bonding in hydrogen fluoride
The strongest hydrogen bond



Hydrogen bonding in water

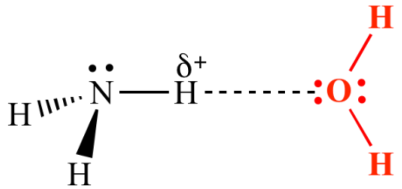
Hydrogen bonds are stronger than other dipole-dipole interactions, but are ten times weaker and twice as long as σ bonds.

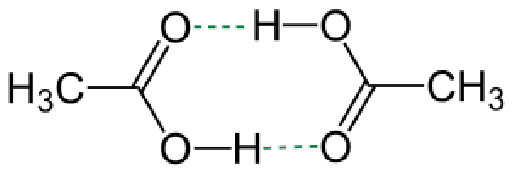
Hydrogen bond energy : 10 – 40 kJ/mol.

Hydrogen bond

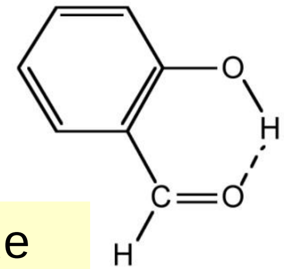
Intermolecular - between two same or different molecules

Intramolecular - within one molecule

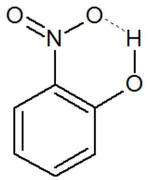




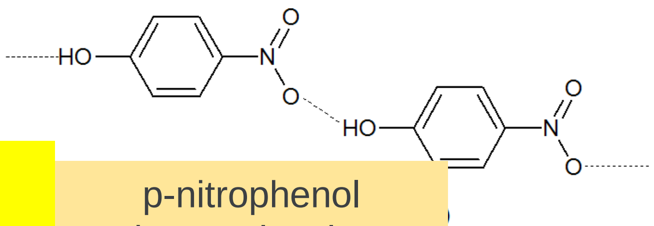
salicylaldehyde



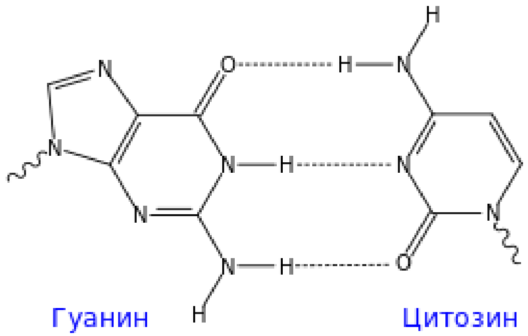
It prevents the association of molecules, the compound has a lower boiling point



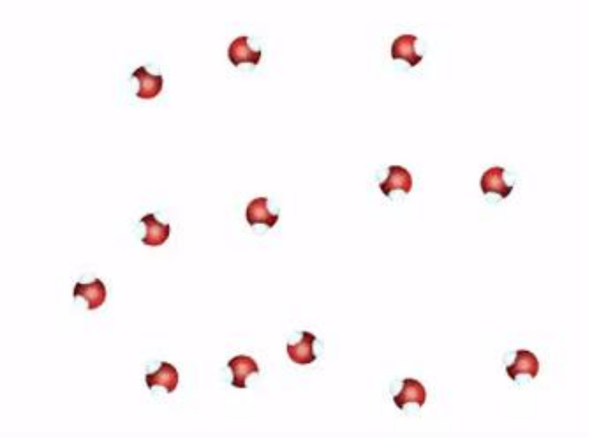
o-nitrophenol intramolecular hydrogen bond



p-nitrophenol intermolecular hydrogen bonding



Hydrogen bonding between nucleic bases



Hydrogen bonding and ice formation

p-nitrophenol boils at a higher temperature, because an intramolecular hydrogen bond is formed between o-nitrophenol molecules.

AMOUNT OF SUBSTANCES
chemical amount

The unit for the amount of substance (n) is mole.

A mole is the amount of a substance that contains as many particles (molecules, atoms, ions) as there are atoms in 12 g of the carbon isotope 12C, which is 6,022,1023 particles

Amount of substance, n – the ratio of the number of particles of that substance to Avogadro's constant (number)

$$n = \frac{N}{N_A}$$

Avogadro's constant

$N_A = 6{,}022 \cdot 10^{23}\ \mathrm{mol^{-1}}$

H

1 mole of hydrogen atoms
$6{,}022 \cdot 10^{23}$ hydrogen atoms

H_2

1 mole of hydrogen molecules
2 moles of hydrogen atoms
$6{,}022 \cdot 10^{23}$ hydrogen molecule
$2 \cdot 6{,}022 \cdot 10^{23}$ hydrogen atoms

H_2O

1 mole of water molecules
$6{,}022 \cdot 10^{23}$ water molecules
$2 \cdot 6{,}022 \cdot 10^{23}$ hydrogen atoms

2 mol hydrogen atoms
$6{,}022 \cdot 10^{23}$ of oxygen atoms 1 mole of oxygen atoms

Molar mass, M – the mass of 1 mole of a substance. The unit for molar mass is g/mol.

$$M = \frac{m}{n}$$

The molar mass of a substance is equal to the relative atomic or relative molecular mass.

$$\begin{aligned} M(\mathrm{H}) &= 1.00797(7) \times M_\mathrm{u} &= 1.00797(7)\ \mathrm{g/mol} \\ M(\mathrm{S}) &= 32.065(5) \times M_\mathrm{u} &= 32.065(5)\ \mathrm{g/mol} \\ M(\mathrm{Cl}) &= 35.453(2) \times M_\mathrm{u} &= 35.453(2)\ \mathrm{g/mol} \\ M(\mathrm{Fe}) &= 55.845(2) \times M_\mathrm{u} &= 55.845(2)\ \mathrm{g/mol} \end{aligned}$$

$M = A_r \cdot \mathrm{g/mol}$

$A_r(N) = 14{,}0$

$M(N) = 14{,}0\ \mathrm{g/mol}$

$M = M_r \cdot \mathrm{g/mol}$

$M_r(NH_3) = 17{,}0$

$M(NH_3) = 17{,}0\ \mathrm{g/mol}$

Molar volume, Vm – the volume occupied by 1 mole of a gaseous substance. The unit for molar volume is dm^3/mol.

$$V_m = \frac{V}{n}$$

The volume of a gas depends on pressure and temperature, which is defined by the gas laws, which apply to ideal gases.

Ideal vs. real gas

- The volume of gas atoms or molecules is negligible.
- There are no attractive Van der Waals forces between for gas molecules.
- It cannot be converted into a liquid or solid state.

- The volume of gas atoms or molecules is not negligible.
- There are attractive Van der Waals forces between atoms and gas molecules.
- It can be translated into a liquid or solid aggregate state.

BOYLE-MARRIOTT'S LAW

R. Boyle

E. Marriott

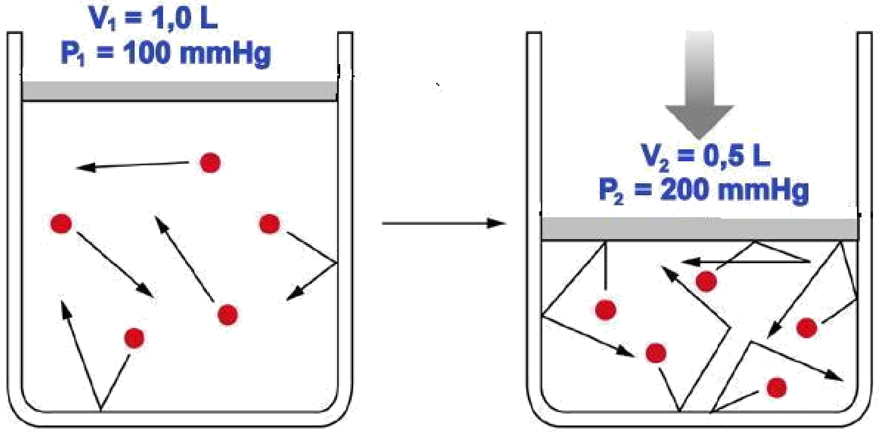
At a constant gas temperature, the volume of a certain amount of gas is inversely proportional to the pressure.

T = const

Isothermal process

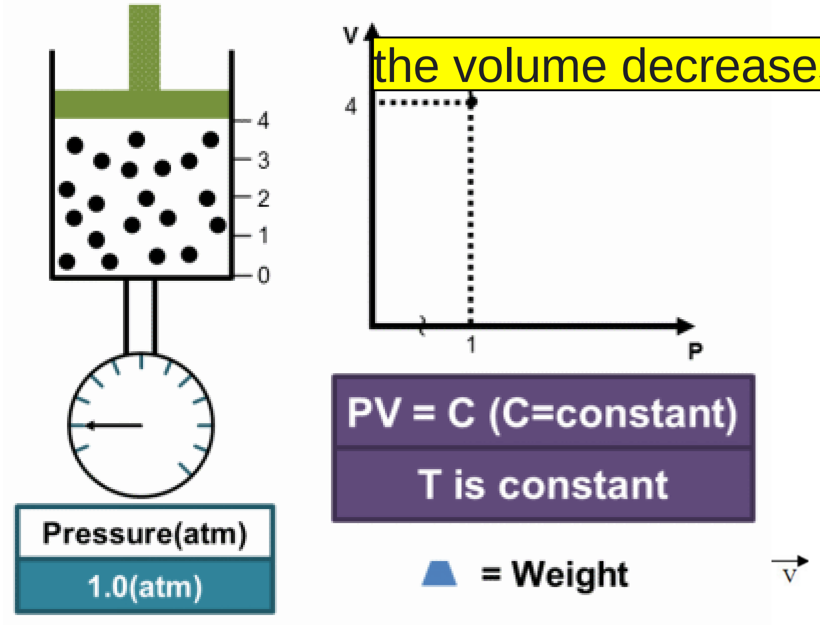
$$p \cdot V = const$$

$$p = \frac{const}{V}$$



the pressure increases

the volume decreases

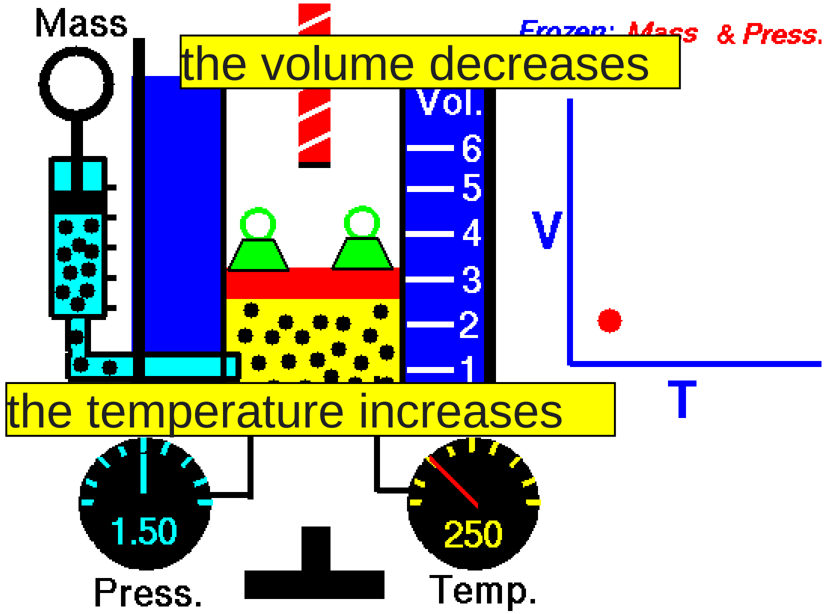


$$p_1V_1 = p_2V_2 = p_3V_3 = p_0V_0$$

CHARLES-GAY-LISAKO'S LAW

Z. Charles

“The volume occupied by a fixed amount of gas is directly proportional to its absolute temperature, if the pressure remains constant.”



J. Gay-Lisak

“Both the pressure and the temperature of an ideal gas are directly proportional, assuming constant mass and volume.”

At constant pressure and constant amount of gas, when the temperature of the gas increases (or decreases) by 1 0 °C, the volume of the gas increases (or decreases) by 1/273.15 part of the volume that the gas had at 0 °C.

p = const

Isobar process

$$V = V_o + \frac{Vo}{273,15} \cdot t$$

Vo = volume of gas at 0 °C

V = volume of gas at °C

IDEAL GAS LAW

IDEAL GAS LAW is valid for ideal gases and to a large extent for real gases.

Boyle-Mariot law

$$V = \frac{const}{p}$$

Charles-Gay-Lissac's law

$$V = const \cdot T$$

Avogadro's law

$$V = const \cdot n$$

$$V = const \cdot \frac{n\,T}{p}$$

$$pV = const \cdot nT$$

IDEAL GAS EQUATION

$$pV = const \cdot nT$$

$$const = R$$

$$pV = nRT$$

P – absolute gas pressure (Pa), *V* – gas volume (m^3),
T - absolute temperature (K),
n – number of moles of gas,
R– universal gas constant (8,314472 $Jmol^{-1}K^{-1}$)

SOLUTIONS - DISPERSION SYSTEMS

Disperse systems - mixtures in which one or more substances are more or less evenly distributed in another substance.

DISPERSION SYSTEMS

- **Dispersed phase**
  Substances that are dispersed in the surrounding substance.
- **Dispersant agent**
  Dispergant
  A substance in which the particles of the dispersed phase are arranged.

Air is a dispersed system:

Nitrogen is a dispersant (the most common)

Other gases are dispersed phases

COARSE-DISPERSE SYSTEMS

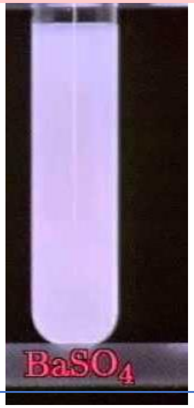
SUSPENSIONS | EMULSIONS

- Dispersed phase particles can also be seen with the naked eye (> 100 nm)
- Unstable systems
- The phases are easily separated

SUSPENSIONS

Dispersed phase: solid aggregate state
Dispersant: liquid aggregate state

muddy river water



$BaSO_4$ in water

EMULSIONS

Dispersed phase: liquid aggregate state
Dispersant: liquid aggregate state

oil and water

Emulsifier is a surfactant that stabilizes emulsions.

Molecular-disperse and ion-disperse systems – REAL SOLUTIONS

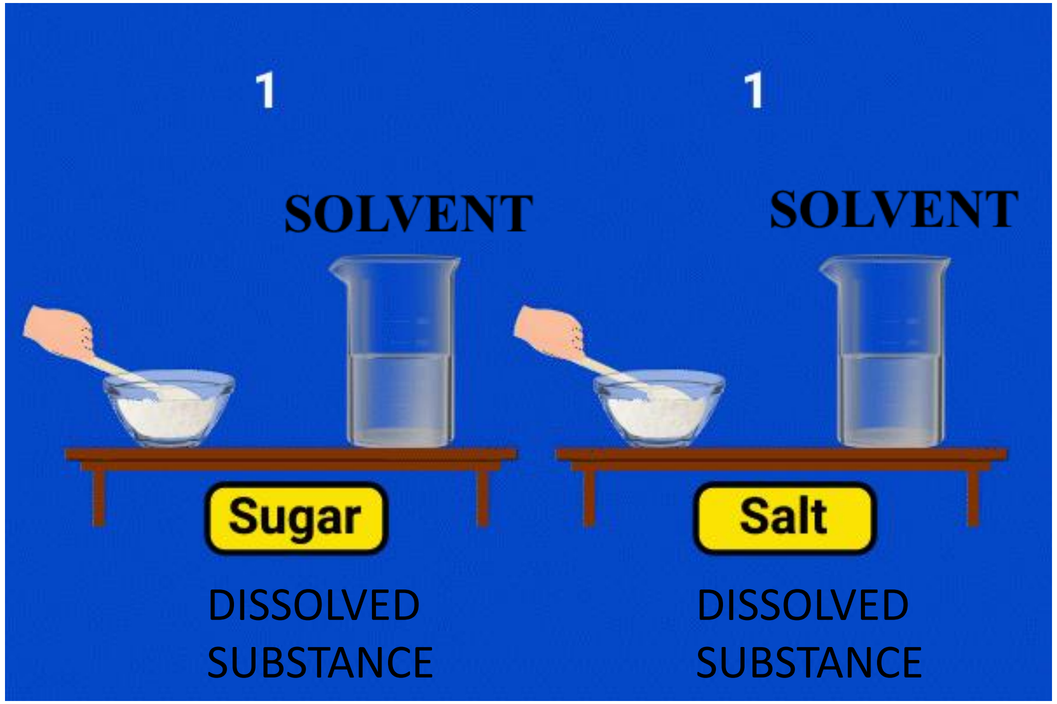
- Dispersed phase particles (molecules or ions) cannot be seen with the naked eye (< 1 nm)
- Homogeneous mixtures
- Stable systems

SOLUTION

→ **SOLVENT** – **dispersion agent**

→ **SOLUTE** – **dispersed phase**

- Solvent is a substance that has the same aggregate state as the solution.
- If more than one substance is in the same aggregate state as the solution, the solvent is the substance that has more.



Determine which substance is a solvent when mixed:

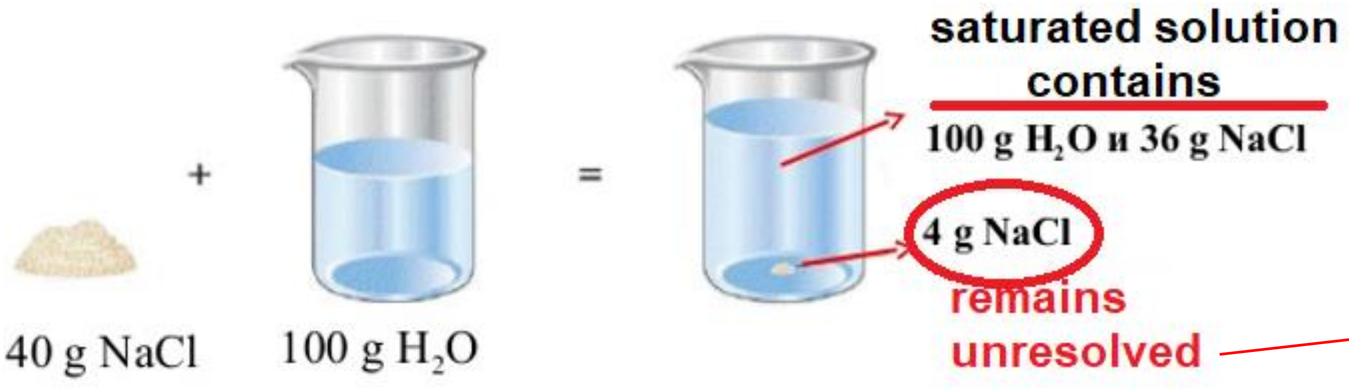
a) 10 g of salt and 100 g of water;
b) b) 140 g of ethanol and 100 g of water;
c) c) 200 g of ethanol and 300 g of water.

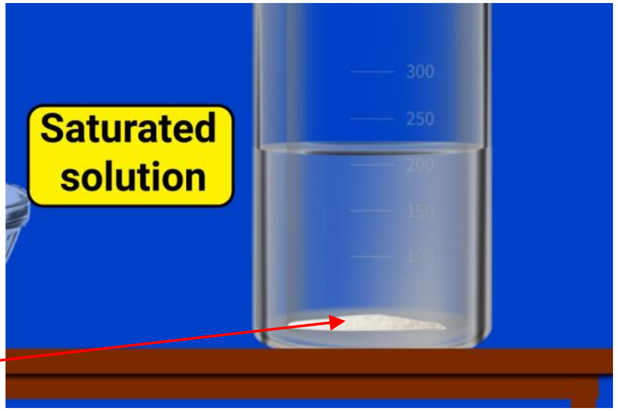
a) Water, because it has the same aggregate state as the solution;
b) Ethanol, because it is present in excess;
c) Water, because it is present in excess.

Saturated solution

- **Solution** containing the maximum possible mass **of solute** in a given mass **of solvent** at a given temperature.

- It is prepared by adding a solute to a solvent until a precipitate appears, whereby the solution above the precipitate is saturated.

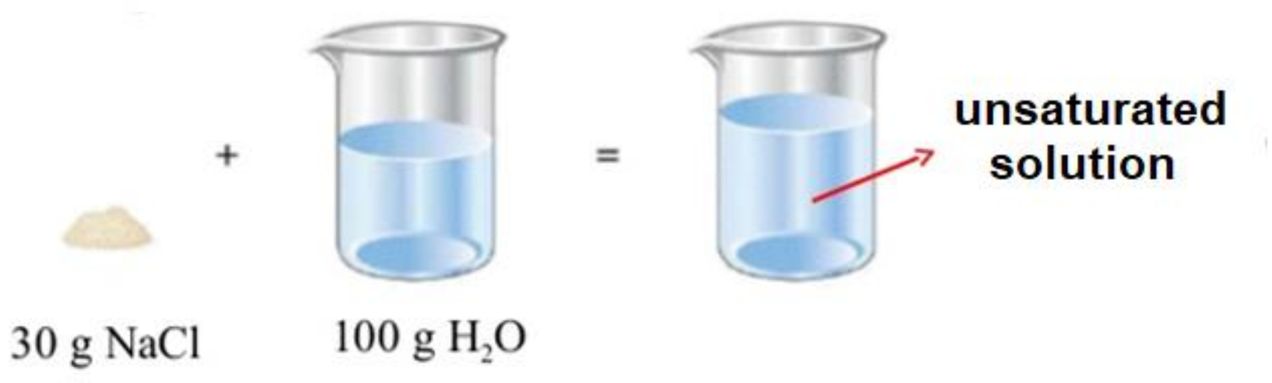




- **The solute content** in a saturated solution is constant

Unsaturated solution

Solution that contains less dissolved substance than the solution at the same temperature.



saturated solution contains

100 g H_2O и 36 g NaCl

Supersaturated solution

- A solution containing more solute in a given mass of solvent than a saturated solution at a given temperature.
- Unstable
- They are made of substances that are difficult to crystallize: $Na_2S_2O_3 \cdot 5H_2O$, $CH_3COONa \cdot H_2O$

Supersaturated solution **can be prepared** by heating a saturated solution, adding more solute, and then cooling it gently.

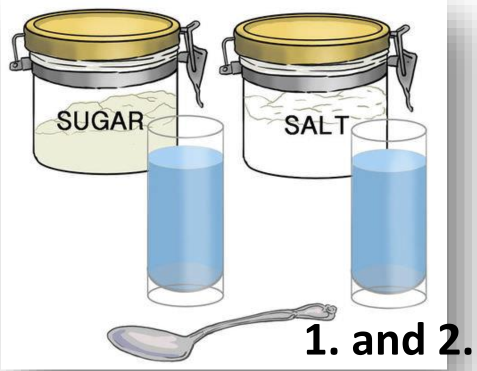
SOLUBILITY (R or S)

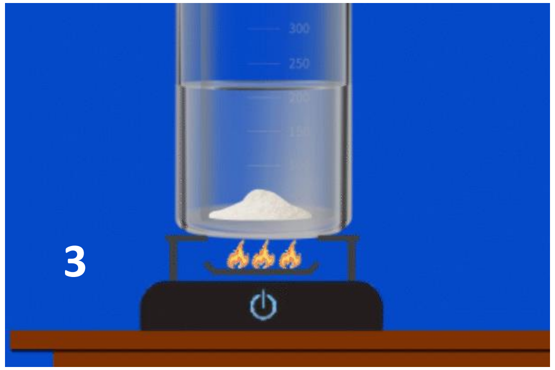
– mass of substance that dissolves in 100 g of solvent at a certain temperature

- Easily soluble substances: > 10 g of dissolved substance per 100 g of solvent
- Poorly soluble substances: 0.01 - 1.00 g of solute per 100 g of solvent
- Insoluble substances < 0.01 g per 100 g of solvent

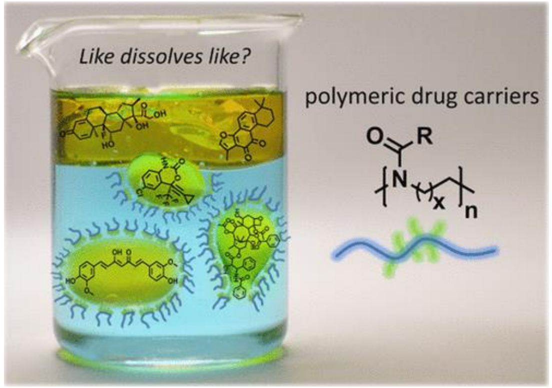
Solubility depends on:

1. nature of the solvent
2. nature of the dissolved substance
3. temperature
4. pressure (of gaseous substances)





„SIMILAR IS DISSOLVED IN SIMILAR“



- Non-polar substances dissolve better in non-polar solvents
- Polar substances dissolve better in polar solvents

WATER (H_2O) - the most important and most widely used polar solvent

Physiological solution, which is used in medicine, is an aqueous solution of sodium chloride.

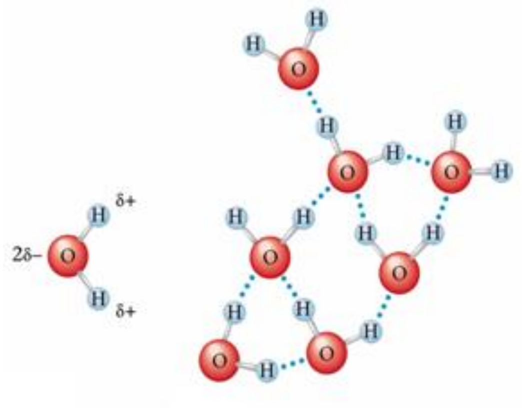
Aqueous solutions, extracts, teas, infusions are used both in medicine and in pharmacy.

Water can be divided into:

soft water, with little dissolved substances (such as rainwater, water that is created by melting snow)

and

hard water, with a lot of dissolved substances. Magnesium and calcium salts contribute the most to water hardness.



MASS FRACTION, ω

MASS FRACTION is the ratio of the mass of a component in the mixture to the total mass of the mixture.

The **MASS FRACTION** of the dissolved substance **in the solution** is the ratio of the mass of the dissolved substance to the mass of the solution.

$$\omega = \frac{\mathbf{m}\,(\text{dissolved substance})}{\mathbf{m}\,(\text{solution})}$$

$$\omega \cdot 100 = \%$$

PERCENTAGE CONCENTRATION – number of grams of dissolved substance in 100 g of solution.

Saline solution

0.9% salt solution of **NaCl**

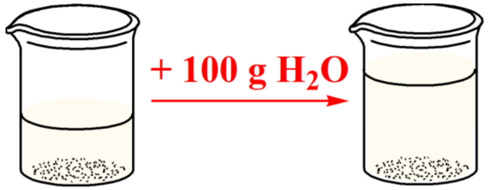
Ringer's solution

0,6% NaCl
0,075% KCl
0,01% $CaCl_2$
0,01% $NaHCO_3$

DILUTION AND CONCENTRATION OF SOLUTIONS OF KNOWN COMPOSITION

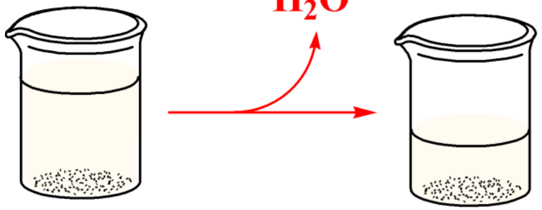
By adding water to a solution of known composition, the percentage concentration **decreases.**

SOLUTION 1
100 g 10% solution
m(dissolved substances) = 10 g



SOLUTION 2
m (solution) = 100 + 100 = 200 g
m(dissolved substances) = 10 g ω =
10/200 = 0.05 → 5% solution

By evaporating water from the solution, its percentage concentration **increases.**



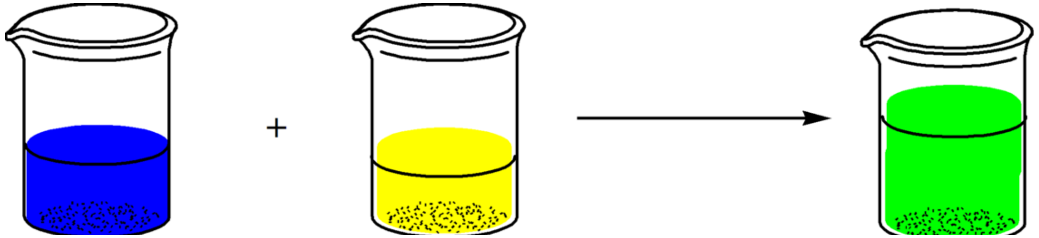
SOLUTION 1 — **SOLUTION 2**

$m(\text{dissolved substances})_1 = m(\text{dissolved substances})_2$

$m(\text{solution})_1 > m(\text{solution})_2 = m(\text{solution})_1 - m(H_2O)$

$\omega_1 < \omega_2$

Mixing solutions of known composition



the volume increases

the concentration changes

SOLUTION 1
$m(\text{d.supstance})_1$
$m(\text{solution})_1$
ω_1

SOLUTION 2
$m(\text{d.substance})_2$
$m(\text{solution})_2$
ω_2

SOLUTION 3
$m(\text{d.substance})_3 = m(\text{d.s.})_1 + m(\text{d.s.})_2$
$m(\text{solution})_3 = m(p)_1 + m(p)_2$
ω_3 $(\omega_1 > \omega_3 > \omega_2)$

Mole fraction, *x*

Mole fraction of a dissolved substance in a solution - the ratio of the amount of that substance to the total number of moles of all substances present in the solution.

$$x = \frac{\mathbf{n}(\text{dissolved substance})}{\mathbf{n}(\text{dissolved substances}) + \mathbf{n}(\text{solvent})}$$

The sum of the mole fractions of all substances in the solution is 1

Mass concentration, *γ*

Mass concentration – the ratio of the mass of the dissolved substance to the volume of the solution.

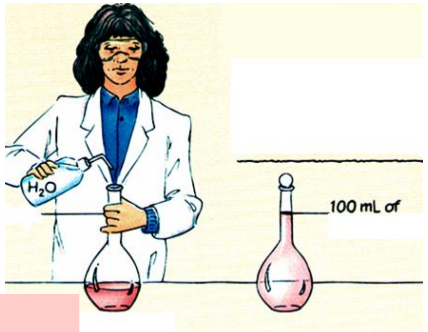
$$\gamma = \frac{\mathbf{m(dissolved\ substance)}}{\mathbf{V(solvent)}}$$

It is most often expressed in **g/dm^3,** but other units are also used **: kg/dm^3, g/cm^3, mg/cm^3**

Molar concentration, *c*

Molar (quantitative) concentration – the ratio of the amount of dissolved substance to the volume of the solution.

$$c = \frac{\text{n(dissolved substance)}}{\text{V(solution)}}$$

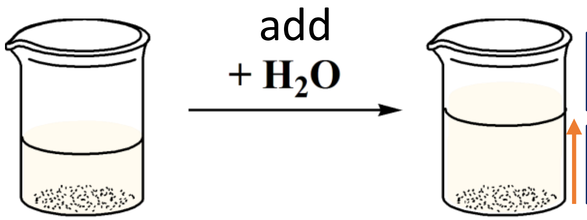


It is expressed in **mol/dm^3 (mol/L) or M**

Molar concentration – number of moles of dissolved substance in **1 L of solution**

Dilution of a solution of known molar concentration

Adding water to a solution does not change **the amount** of solute, but only **the volume** of the solution



the volume increases

the concentration decreases

SOLUTION 1 **SOLUTION 2**

$$\text{n(dissolved substance)}_1 = \text{n(dissolved substance)}$$

$$c_1V_1 = c_2V_2$$

Molal concentration, *b*

Molal concentration represents the ratio of the amount of dissolved substance to the mass of the solvent.

$$b = \frac{n(\text{dissolved substance})}{m(\text{solvent})}$$

Molal concentration – number of moles of dissolved substance in 1 kg of solvent

It is expressed in **mol/kg or mmol/g**

ppm – parts per million

ppm – number of solute particles per million solution particles

1 *ppm* = 1 mg/kg = 1 µg/g = 1 mg/L = 1 µg/mL

ppb – parts per billion

ppb – number of solute particles per billion solution particles

1 *ppb* = 1 µg/kg = 1 ng/g = 1 µg/L = 1 ng/mL

Preparation of the solution

Calculate the molality of a 27.0% sulfuric acid solution

27% solution H_2SO_4 contains 27 g H_2SO_4 in 100 g of solution, or 27 g H_2SO_4 and 73 g of water.

The molality of a solution represents the number of moles of solute in one kilogram of solvent.

27 g H_2SO_4:73 g water=x:1000 g water (mass of pure substance per kilogram of solvent)

X= 370 g H_2SO_4 (it is necessary to convert this mass into moles), Mr (H_2SO_4)=98)

1 mol:98 g=x:370 g
X=3,77 mol

Molality of 27% sulfuric acid solution is 3.77 mol/kg

Colligative properties of solutions

Colligative properties of solutions - properties of dilute solutions that depend only on the number of particles in the solution, and do not depend on the type of particles.

1) Lowering of the vapor pressure of the solvent above the solution
2) Freezing point depression of the solution
3) Boiling point elevation of the solution
4) Osmotic pressure

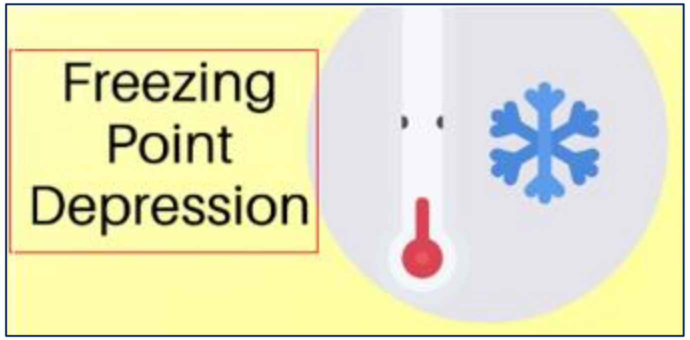
Dissolved substances

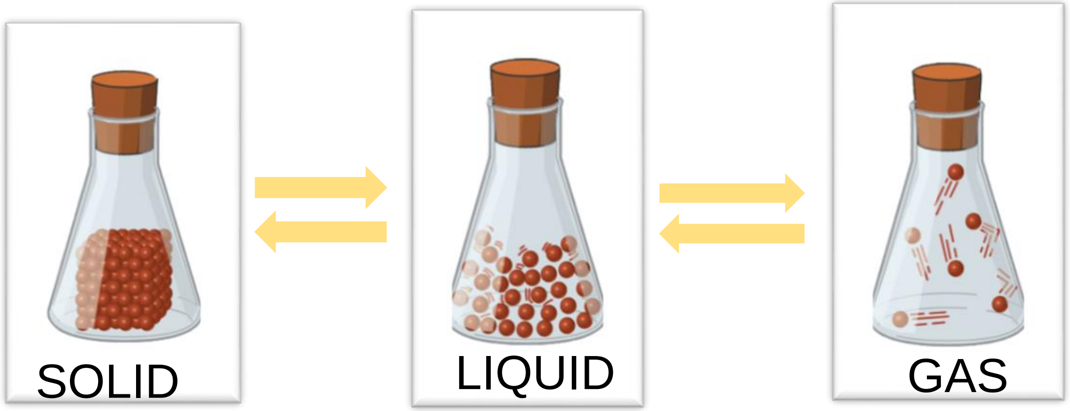
NON ELECTROLYTES

They do not dissociate into ions in water

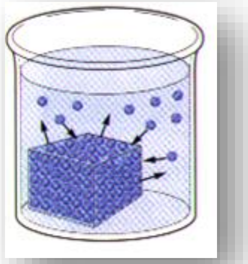
ELECTROLYTES

They dissociate into ions in water and their aqueous solutions conduct electricity

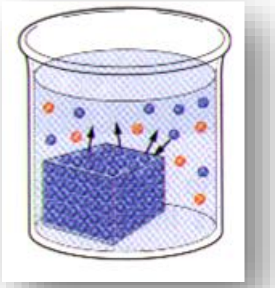




Freezing point (Melting point) – the temperature at which the liquid and solid phases are in equilibrium.

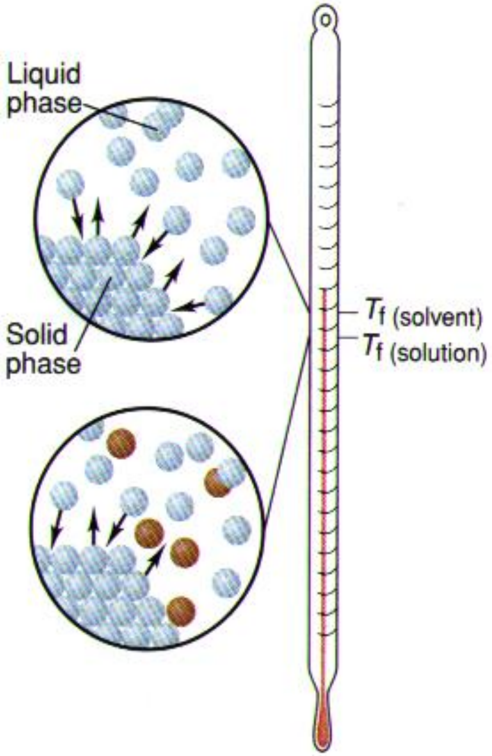


$T_m(solvent)$



$T_m(solution)$

$$T_m(solution) < T_m(solvent)$$



$$\Delta T_m = T_m(solvent) - T_m(solution)$$

$$\Delta T_m = K_k \cdot b$$

ΔT_m – lowering the freezing point of the solution

K_k – cryoscopic constant (K·kg/mol)

b – molality (mol/kg)

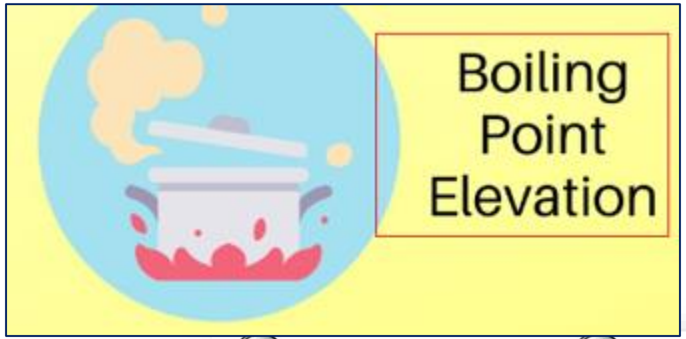
The lowering of the freezing point of non-electrolyte solutions is directly proportional to the molality of the solution.

Cryoscopic constant, K_k – lowering the freezing point of the solution when its molality is equal to 1 mol/kg and is a characteristic value for each solvent.

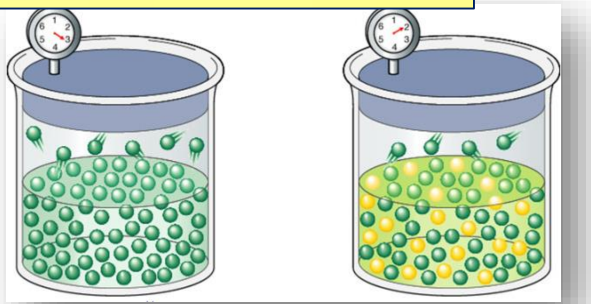
Applications in everyday life

antifreeze

street salting in winter



Boiling point (Tm) - the temperature at which the vapor pressure of a liquid is equal to atmospheric pressure (101.325 kPa)



$T_k(solvent)$ $T_k(solution)$

$p_0 > p$

↓

$T_k(solvent) < T_\kappa(solution)$

$\Delta T_k = T_k(solution) - T_k(solvent)$

$\Delta T_\kappa = K_e \cdot b$

ΔT_κ – **Boiling point elevation**

K_e – ebullioscopic constant (K·kg/mol)

b – molality (mol/kg)

The boiling point elevation of non-electrolyte solutions is directly proportional to the molality of the solution.

Ebulioscopic constant, K_e – elevation of the boiling point of the solution when its molality is equal to 1 mol/kg and is a characteristic value for each solvent.

Diffusion

Diffusion – spontaneous tendency of heterogeneous systems to become homogeneous.

The result of the system to achieve maximum entropy.

Molecules move from an area of higher to an area of lower concentration.

Dialysis

Dialysis - spontaneous movement of small molecules through a semipermeable membrane from an area of higher to an area of lower concentration.

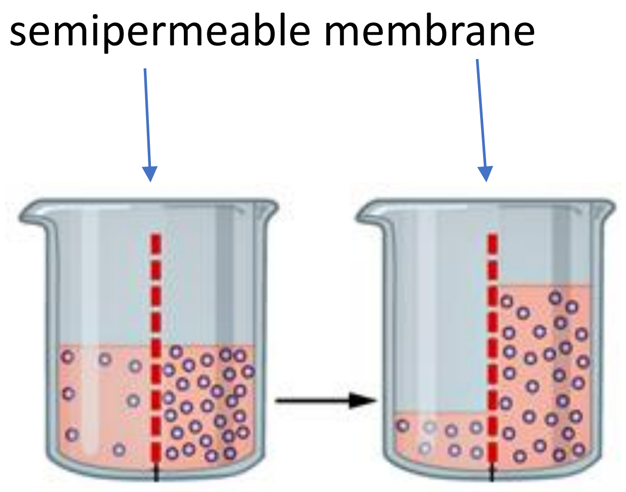
Lower concentration

Higher concentration

semipermeable
membrane

The membrane is not permeable for macromolecules.

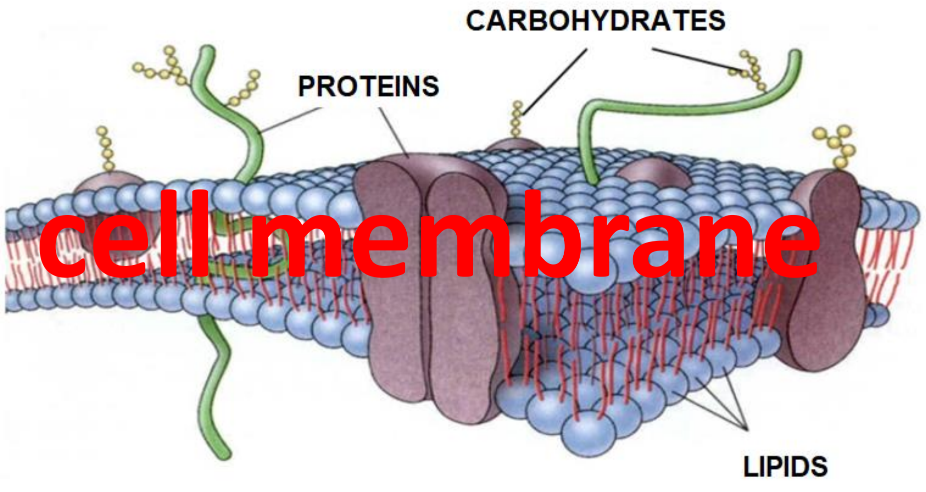
Osmosis

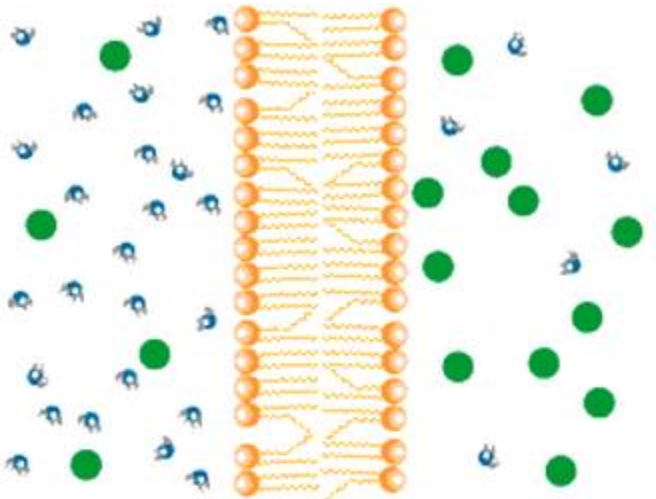


Osmosis - the spontaneous transition of a solvent into a solution or a more dilute solution into a more concentrated solution, when they are separated by a semipermeable membrane.

The membrane is permeable to solvent molecules, but not for solute molecules.

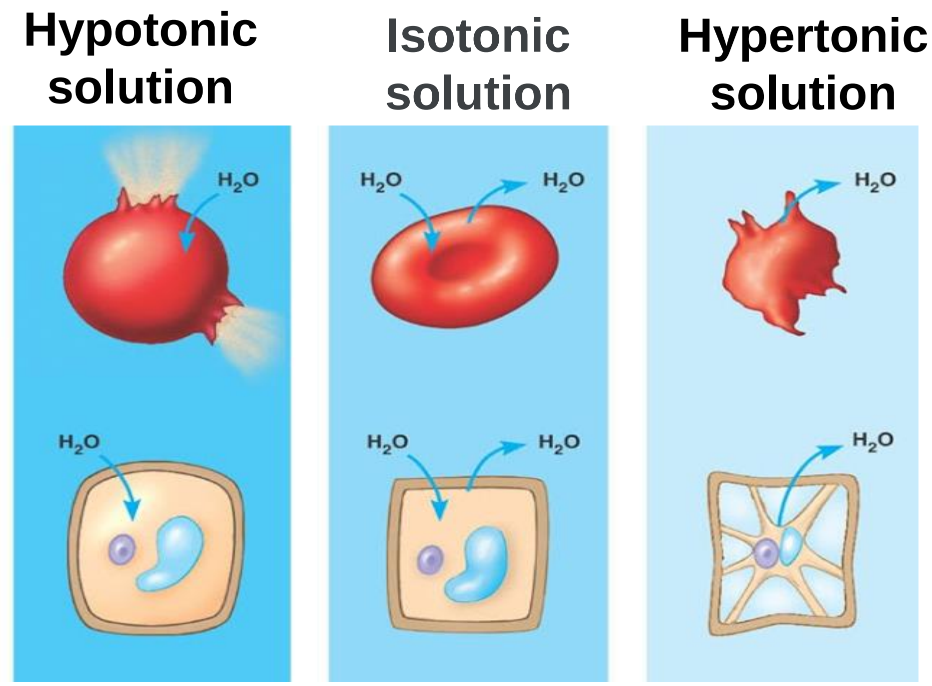
Membrane: cellophane, rubber, cellulose acetate, animal and ceramic membranes.





The most important membrane in biology and medicine is the **cell membrane**

Colligative properties of electrolyte solution



Hypotonic solution contains a lower concentration of solute compared to another solution (eg cell cytoplasm). When a cell is in a hypotonic solution, water diffuses into the cell and the cell itself swells.

Hypertonic solution contains a higher concentration of solute compared to another solution (eg cell cytoplasm). When a cell is placed in a hypertonic solution, water diffuses out of the cell and the cell itself shrinks.

Isotonic solution contains the same concentration of solute as another solution (eg cell cytoplasm). When a cell is in an isotonic solution, water diffuses into and out of the cell at the same rate.

Physiological solution, 0.9% NaCl, is isotonic with blood plasma.

Chemical reaction

Chemical reaction is a process in which one or more substances (reactants) are converted to one or more different substances (products).

The chemical reaction is a reaction between an acid and a base, in which a salt is formed as a product.

$$H_2SO_{4(aq)} + 2NaOH_{(aq)} \rightleftarrows Na_2SO_{4(aq)} + 2H_2O_{(l)}$$

This reaction is called a neutralization reaction and can also be written in the ionic form:

$$\mathbf{2H^+} + SO_4^{2-} + 2Na^+ + \mathbf{2OH^-} \rightleftarrows 2Na^+ + SO_4^{2-} + 2H_2O$$

This reaction belongs to protolytic reactions (proton exchange reactions).

Chemical reactions can be divided into three groups:

1. Chemical reactions in which dissociation and association of molecules, atoms and ions occur
2. Oxido-reduction reactions
3. Complex reactions that include:
    a) protolytic reactions
    b) precipitation and dissolution reactions
    c) complex formation and decomposition reactions (complex reactions)

Chemical reactions can be divided into reversible and irreversible reactions.

$H_2SO_{4(aq)} + 2NaOH_{(aq)} \rightleftarrows Na_2SO_{4(aq)} + 2H_2O_{(l)}$ reversible reaction

Dissociation of hydrochloric acid is ireversibile reaction.

burning is an irreversible reaction.

OXIDO-REDUCTION REACTIONS

Processes in which oxidation numbers of elements change (due to the transfer of electrons from one atom or ion to another atom or ion) are called oxidation-reduction processes or oxidation-reduction reactions (redox reactions).

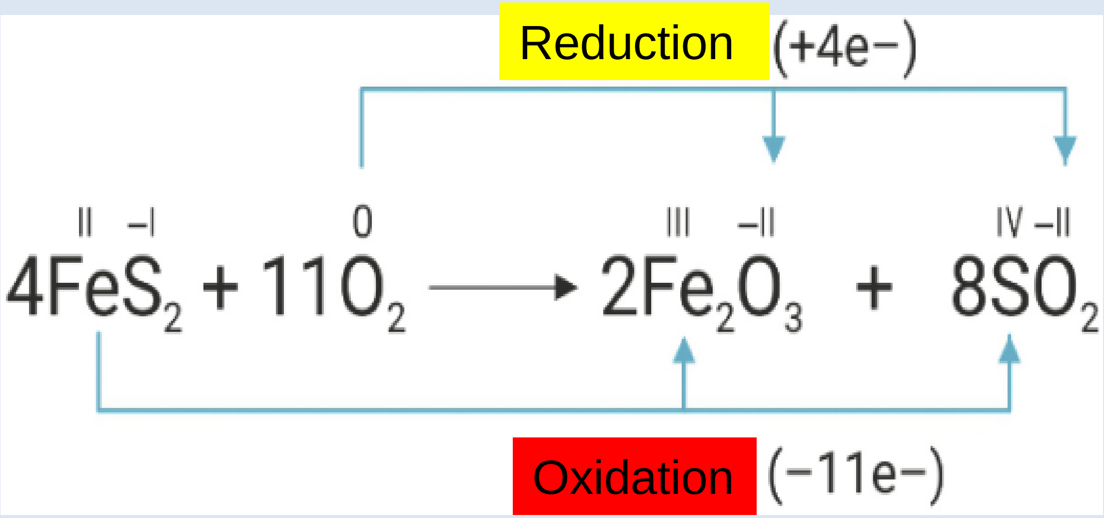
The oxidation number of an element shows the oxidation state the element is in.

$K_2Cr_2O_7$: $2\cdot(+1) + 2\cdot(+6) + 7\cdot(-2) = 0$ or

H_2SO_4: $2\cdot(+1) + 1\cdot(+6) + 4\cdot(-2) = 0$

Oxidation reaction represents the process of releasing an electron from an atom (molecule or ion), whereby the oxidation number increases.

Reduction reaction is the process of receiving an electron by an atom (molecule or ion), whereby the oxidation number decreases.



The following reaction is also a redox reaction...

$8\ H^{+} + MnO_4^{-} + 5\ Fe^{2+} \rightarrow Mn^{2+} + 5\ Fe^{3+} + 4\ H_2O$

...which can be shown as an oxidation reaction and a reduction reaction:

reduction: $8\ H^{+} + MnO_4^{-} + 5\ e^{-} \rightarrow Mn^{2+} + 4\ H_2O$

oxidation: $5\ Fe^{2+} \rightarrow 5\ Fe^{3+} + 5\ e^{-}$

Problem 1. Determine the coefficients in the following redox reaction:

$Cu + HNO_3 \rightarrow Cu(NO_3)_2 + NO + H_2O$

Answer: *Copper is a reducing agent and nitric acid is an oxidizing agent.*

$3Cu + 8HNO_3 \rightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O$

Problem 2. In the following reaction, potassium permanganate is an oxidizing agent, and hydrogen peroxide is a reducing agent. Determine the coefficients in this reaction.

$KMnO_4 + H_2O_2 + H_2SO_4 \rightarrow O_2 + MnSO_4 + K_2SO_4 + H_2O$

Answer: $2KMnO_4 + 5H_2O_2 + 3H_2SO_4 \rightarrow 5O_2 + 2MnSO_4 + K_2SO_4 + 8H_2O$

Based on the above examples, it can be concluded that metals are reducing agents, and potassium permanganate is an oxidizing agent. Non-metals are good oxidizing agents (fluorine, chlorine, bromine, iodine, oxygen and ozone).

Redox reactions in living systems

Oxido-reduction processes are the basis of the functioning of most human cells.

These processes create large amounts of adenosine triphosphate (ATP), which is necessary for human cells.

In the processes of respiration in the cell, a large amount of energy is released that is used for the synthesis of ATP (so-called oxidative phosphorylation).

Reaction rate

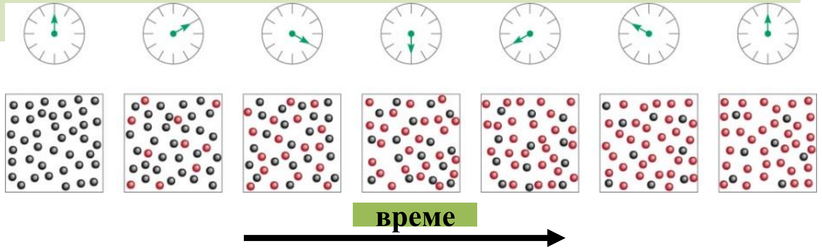
Chemical kinetics - a part of chemistry that deals with the study of the speed of chemical reactions and the their mechanism.

explosion - instantaneous chemical reaction

rusting of iron - a slow chemical reaction

The Reaction Rate is the measure of the change in concentration of the reactants or the change in concentration of the products per unit time. *v*

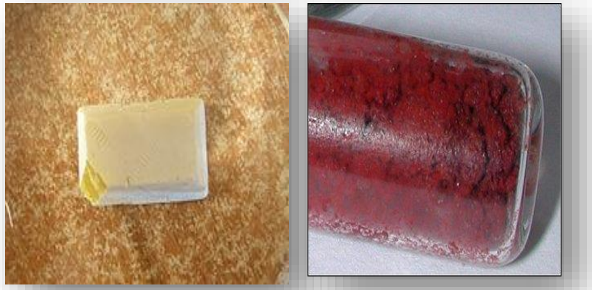
Unit for the reaction rate is the mol dm^{-3} s^{-1}



$$A \rightarrow B \qquad v = \frac{\Delta c}{\Delta t}$$

Factors that affect the rate of a chemical reaction

- Nature of reactants
- Crushing of solid substances
- Temperature
- Concentration of reactants
- Pressure of gaseous substances
- Container volume
- Radiation



Influence of the nature of the reactants

The speed at which existing bonds will be broken and new bonds will be formed depends on the properties of the reactant molecules.

Formation of reaction product molecules

$$A \rightarrow B + C$$

$$v = kc_A$$

Strong acid

$Zn + 2HCl \rightarrow ZnCl_2 + H_2\uparrow$

Weak acid

$Zn + 2CH_3COOH \rightarrow Zn(CH_3COO)_2 + H_2\uparrow$

The rate of the reaction depends on the strength of the acid.

The reaction is faster in the presence of strong acid HCl

- General reaction:

$$aA + bB = cC + dD$$

$$v = kc_A{}^a . kc_B{}^b$$

Burning rate

- The rate of a chemical reaction is proportional to the product of the molar concentrations of reactants graded by stoichiometric coefficients.

- It was experimentally determined that when the temperature rises by 10 ℃, the speed of the chemical reaction increases 2-4 times.

- Catalysts are substances that accelerate a chemical reaction and remain chemically unchanged after the reaction.