Inorganic chemistry

Chemistry of bioelements

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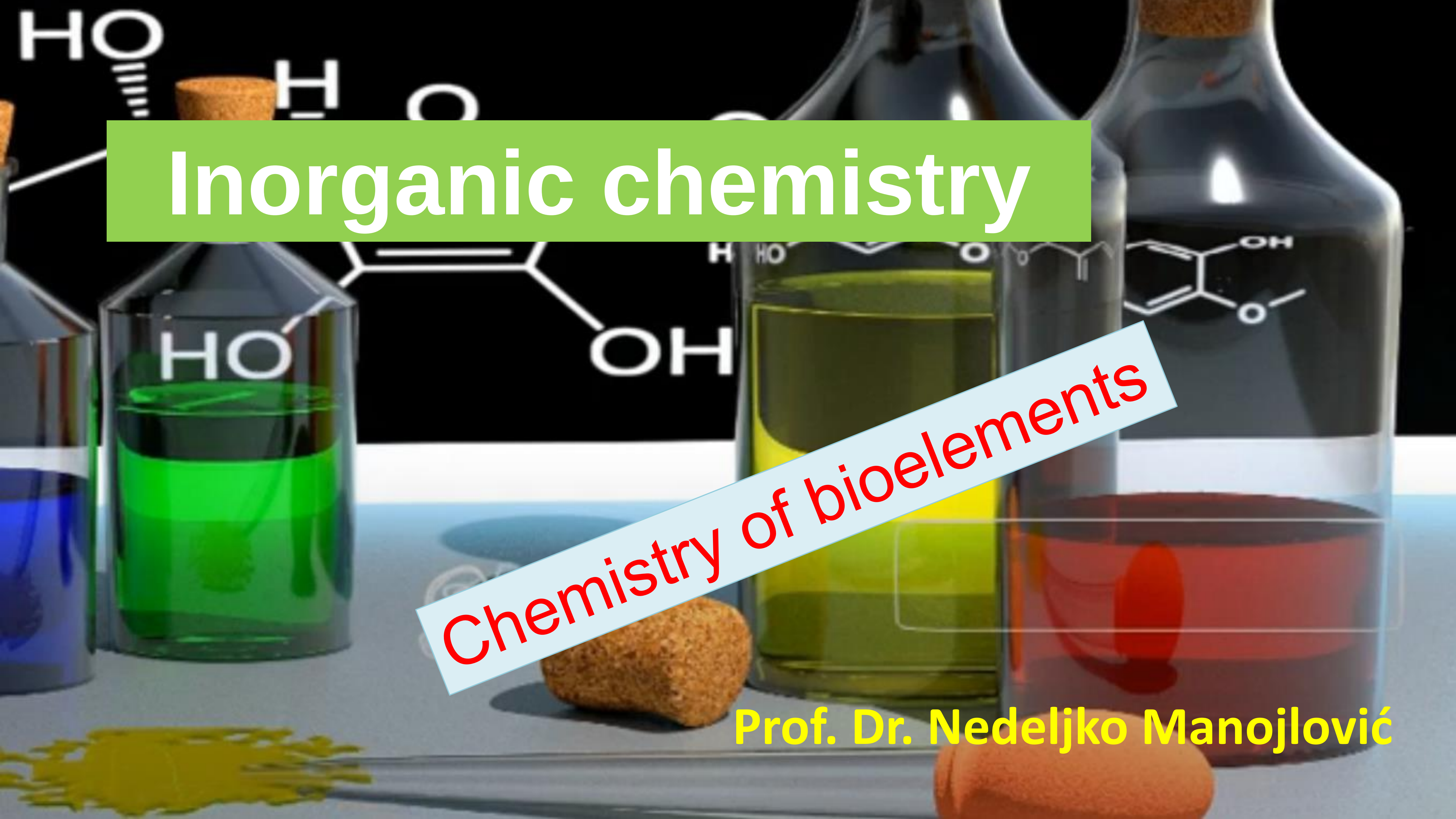


INORGANIC COMPOUNDS

- There are several hundreds of thousands of inorganic compounds but many times less than organic compounds.

- INORGANIC CHEMISTRY studies the chemical elements and their compounds that make up non-living things, including some carbon compounds (e.g. CO, CO_2, H_2CO_3 and HCN, their salts and carbides).

rocks

Inorganic compounds are divided into:

1. compounds that contain 2 types of elements in the molecule (binary)
2. compounds that contain more than 2 types of elements in the molecule (complex).

The most important inorganic compounds include water, acids, bases, salts, oxides, hydrides and others.

Inorganic compounds
Stone and water

Inorganic compounds

Compounds containing 2 types of elements in a molecule	Compounds that contain more than 2 types of elements in a molecule
BINARY	**COMPLEX**

COMPLEX INORGANIC COMPOUNDS

- ACIDS
- BASES
- SALT

stalactites

stalagmites

calcium carbonate → SALT

ACIDS

Arrhenius theory of electrolytic dissociation

Acid is an electrolyte that, upon dissociation in an aqueous solution, gives hydrogen H^+ ions as the only positive ions.

$$HCl \rightarrow H^+ + Cl^-$$

$$H_2SO_4 \rightarrow H^+ + HSO_4^-$$

Strong electrolyte
complete dissociation

$$CH_3COOH \leftrightarrows H^+ + CH_3COO^-$$

Weak electrolyte
partial dissociation

vinegar

9 %

Protolithic theory - Brønsted-Lowry theory

Acid - a substance that, in reaction with a base, transfers a proton (H^+) to the base, i.e. **it is a proton donor**.

The equation of protolithic reaction

$$\underset{\text{acid 1}}{HA} + \underset{\text{base 2}}{B} \leftrightarrows \underset{\text{base 1}}{A^-} + \underset{\text{acid 2}}{BH^+}$$

HA/A^- and B/BH^+ - conjugate pairs

A^- is the conjugate base of an acid **HA**

BH^+ is the conjugate acid of the base **B**

Lewis theory

Acid - a molecule or ion that can receive an electron pair from another molecule or ion, i.e. it is an electron pair acceptor.

Lewis acid

Lewis base

Hydronium ion

$$H^+ + H_2\ddot{O}: \rightarrow H_3O^+$$

How are acids classified?

a) According to strength

STRONG ACIDS - dissociate almost completely in aqueous solution

HCl, HBr, HI, H_2SO_4, HNO_3, $HClO_3$, $HClO_4$ etc.

$$HCl \rightarrow H^+ + Cl^-$$

$$H_2SO_4 \rightarrow H^+ + HSO_4^-$$

WEAK ACIDS - in aqueous solution they are found mostly in the form of undissociated molecules (only a small part is dissociated into ions)

HF, $HClO$, H_2SO_3, H_2S, H_3PO_4, CH_3COOH etc.

$$H_2S \leftrightarrows H^+ + HS^-$$

б) According to composition (some contain oxygen and some do not)

OXYGEN-CONTAINING ACID – contain oxygen

H_2SO_3, H_2SO_4 HNO_2, HNO_3 $HClO$, $HClO_2$, $HClO_3$, $HClO_4$

The strength of these acids increases with the increase in the number of oxygen atoms.

ACIDS THAT DO NOT CONTAIN OXYGEN

HF, HCl, HBr, HI

- **Sulfuric Acid** (H_2SO_4)
- Hydrochloric Acid (HCl)
- **Hydroiodic Acid** (HI)
- Nitric Acid (HNO_3)
- **Hydrobromic Acid** (HBr)
- Chloric Acid ($HClO_3$)
- **Perchloric Acid** ($HClO_4$)

Strong acids completely dissociate in aqueous solution.

The reaction arrow points only to the right.

All of the reactant (acid) is ionized into product.

$HCl \rightarrow H^+ + Cl^-$
$HNO_3 \rightarrow H^+ + NO_3^-$
$H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$

$HO_2C_2O_2H$ - oxalic acid ($H_2C_2O_4$)
H_2SO_3 - sulfurous acid
HSO_4^- - hydrogen sulfate ion
H_3PO_4 - phosphoric acid
HNO_2 - nitrous acid
HF - hydrofluoric acid
HCO_2H - methanoic acid
C_6H_5COOH - benzoic acid
CH_3COOH - acetic acid
HCOOH - formic acid
HF – hydrofluoric acid
HCN – hydrocyanic acid
H_2S - hydrosulfuric acid

Weak acids incompletely dissociate in aqueous solution.

An example reaction is the dissociation of ethanoic acid in water to produce hydroxonium cations and ethanoate anions:

$$CH_3COOH + H_2O \leftrightarrows H_3O^+ + CH_3COO^-$$

back reaction

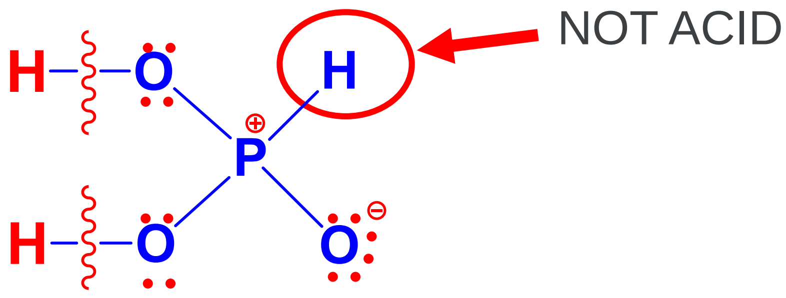
3) According to the number of hydrogen atoms

monoprotic (monobasic, HCl, HNO_2, HNO_3, $HClO_4$),

diprotic (dibasic, H_2S, H_2SO_3, H_2SO_4, H_2CO_3, H_2PHO_3) и

triprotic (three-proton, three-base, H_3AsO_4, H_3PO_4).

H_2PHO_3 (H_3PO_3) belongs to diprotic acids



These salts do not exist Na_3PO_3, K_3PO_3, $Ca_3(PO_3)_2$

These salts exist Na_2PHO_3, K_2PHO_3, $CaPHO_3$

Reactions

1) Reaction with bases - neutralization

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$$

2) Reaction with basic and amphoteric oxides

$$2HCl + CaO \rightarrow CaCl_2 + H_2O$$

$$6HCl + Al_2O_3 \rightarrow 2AlCl_3 + 3H_2O$$

3) Reaction with metals

$$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$$

$$Fe + 2HCl \rightarrow FeCl_2 + H_2$$

Bases

Arrhenius theory of electrolytic dissociation

Base – an electrolyte that, upon dissociation in an aqueous solution, gives **OH^-** ions as the only negative ions.

$$NaOH \rightarrow Na^+ + OH^-$$

$$Ba(OH)_2 \rightarrow Ba^{2+} + 2OH^-$$

Strong electrolyte complete dissociation

$$Zn(OH)_2 \leftrightarrows Zn^{2+} + 2OH^-$$

Weak electrolyte partial dissociation

Protolithic theory - Brønsted-Lowry theory

Base – a substance that receives a proton (**H^+**) from the acid in a reaction with an acid, i.e. it is a proton acceptor.

The equation of protolithic reaction

$$NH_3 + H_2O \leftrightarrows NH_4^+ + OH^-$$

base 1 | acid 2 | acid 1 | base 2

NH_4^+ is the conjugate acid of the base **NH_3**

Lewis theory

Base – a molecule or ion that can transfer an electron pair to another molecule or ion, i.e. It is an electron pair donor.

Lewis acid

$$H^+ + H_2\ddot{O}: \rightarrow H_3O^+$$

Lewis base

How are the bases classified?

а) According to the type of substance

IONIC HYDROXIDES

$NaOH$, KOH, $Ba(OH)_2$

MOLECULAR SUBSTANCES

NH_3, C_5H_5N, $C_6H_5NH_2$

в) According to the number of OH^- groups

MONOHYDROXIDE (monoacid)
DIHYDROXY (diacid)
TRIHYDROXY (triacids)

б) According to strength

STRONG BASES - they dissociate almost completely in aqueous solution. These are alkaline bases and alkaline earth metals, with the exception of beryllium hydroxide.

$$NaOH \rightarrow Na^+ + OH^-$$

$$Ba(OH)_2 \rightarrow Ba^{2+} + 2OH^-$$

WEAK BASES - in aqueous solution they are found mostly in the form of undissociated molecules (only a small part is dissociated into ions).

$$Zn(OH)_2 \leftrightarrows Zn^{2+} + 2OH^-$$

$NaOH$, KOH, $Mg(OH)_2$, $Cu(OH)_2$
$Al(OH)_3$, $Fe(OH)_3$

Preparation of bases

1) Reaction of basic oxides and water

$$Na_2O + H_2O \rightarrow 2NaOH$$

$$K_2O + H_2O \rightarrow 2KOH$$

$$CaO + H_2O \rightarrow Ca(OH)_2$$

2) Dissolving alkaline and alkaline earth metals (except Be) in water

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

$$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$$

Sodium hydroxide (NaOH) is used in the production of soap, paper and artificial silk.

Calcium hydroxide (slaked lime) is used to produce bleaching powder and to remove sulfur dioxide, which is a component of exhaust gases from power plants and factories.

Amphoteric hydroxides

Amphotericity – the ability of a substance to react with both an acid and a base.

$Be(OH)_2$ – beryllium hydroxide
$Al(OH)_3$ – aluminum
$Sn(OH)_2$ – tin(II)-hydroxide
$Pb(OH)_2$ – lead(II)-hydroxide
$Cr(OH)_3$ – chromium(III)-hydroxide
$Zn(OH)_2$ – zinc hydroxide

$$Al(OH)_3 + 3HCl \rightarrow AlCl_3 + 3H_2O$$

$$Al(OH)_3 + NaOH \rightarrow Na[Al(OH)_4]$$

Aluminum hydroxide is an amphoteric substance that belongs to weak bases, it is not toxic, so it is used in medicine as an integral part of a medicine to neutralize excess acid in the stomach. Because its sediment is gelatinous and can bind larger particles, it is used for water purification.

pH value

For practical reasons, the Danish chemist Serensen introduces the pH scale as a way of expressing the acidity of a solution.

pH value – the negative logarithm of the numerical value of the hydronium ion concentration

$$pH = -\log[H_3O^+]$$

$$[H_3O^+] = 10^{-pH}$$

Example

a) If $[H_3O^+] = 1{,}0 \cdot 10^{-13}$ mol/dm^3,

$pH = -\log[H_3O^+] = -\log 1{,}0 \cdot 10^{-13} = 13{,}0$

б) If $[H_3O^+] = 1{,}0$ mol/dm^3,

$pH = -\log[H_3O^+] = -\log 1{,}0 = 0{,}0$

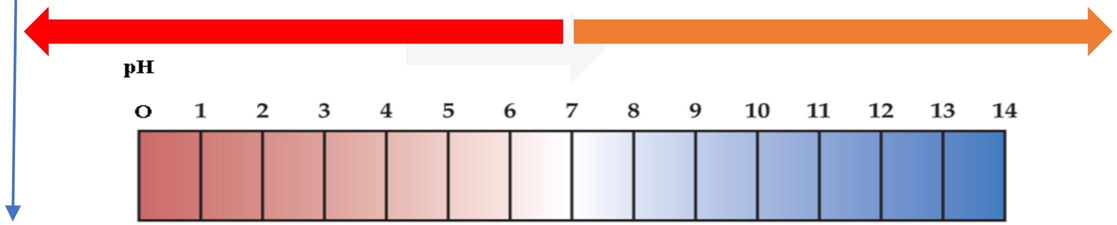
neutral solution: $[H_3O^+] = 1 \cdot 10^{-7}$ mol/dm^3, pH = 7

acid solution: $[H_3O^+] > 1 \cdot 10^{-7}$ mol/dm^3, pH < 7

pH скала

increasing acidity

increasing basicity



$[H_3O^+]$ 1 10^{-7} 10^{-14}

basic solution: $[H_3O^+] < 1 \cdot 10^{-7}$ mol/dm^3, pH > 7

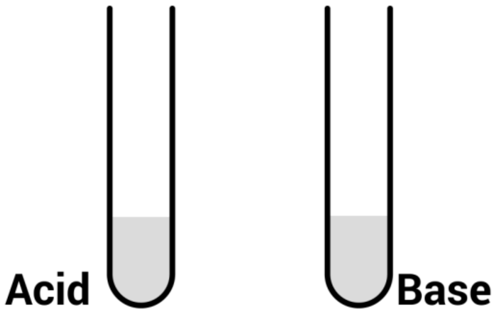
pOH value – the negative logarithm of the numerical value of the hydroxide ion concentration

$$\mathbf{pOH = -log[OH^-]}$$

pK value – the negative logarithm of the numerical value of the equilibrium constant K

$$\mathbf{p\mathit{K} = -log\mathit{K}}$$

$$K_w = [H_3O^+][OH^-] \,/\, \cdot\, (-log)$$



red

blue

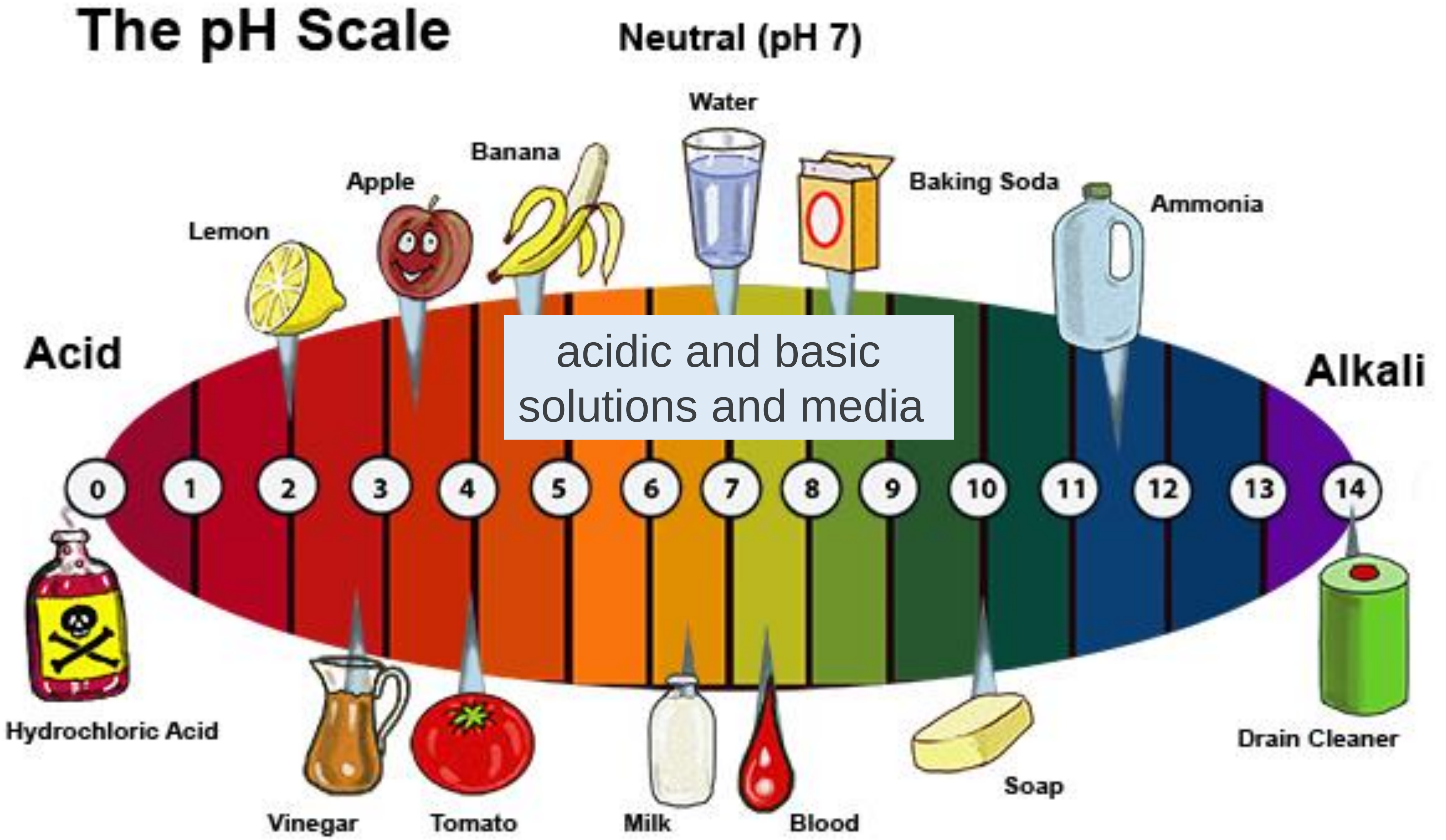
$$-logK_w = -log[H_3O^+] + (-log[OH^-])$$

$$pK_w = pH + pOH$$

$$\mathbf{pH + pOH = 14}$$

Ka is the acid dissociation constant.
Kb is the base dissociation constant.
Kw is the self-ionization constant of water.

acidic and basic solutions and media



pH range of the biological fluids

Biological Fluid	pH
Blood	7.35 - 7.40
Tears	7.20 - 7.40
Saliva	6.40 - 7.00
Gastric juice	1.50 - 3.00
Pancreatic juice	7.50 - 8.00
Interstitial fluid	7.20 - 7.40
Intracellular fluid	6.50 - 6.90
Urine	5.00 - 7.50
Cerebrospinal fluid	7.20 - 7.40

pH meter measures how acidic or basic a solution is.

Salt

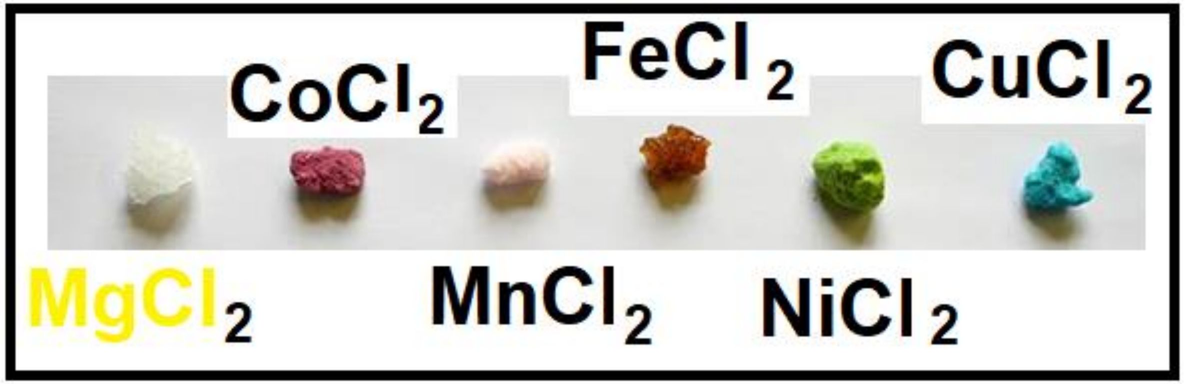
Salt hydrolysis - the reaction of salt with water, resulting in an acid and a base

hydrolysis

$$BA + H_2O \rightleftharpoons HA + BOH$$

neutralization

salt — acid — base



It is reaction of salt ions with water, resulting in a weakly dissociated compound (weak acid or base) and changing the pH of the solution.

Strong acids and bases in aqueous solution hydrolyze (react with water)

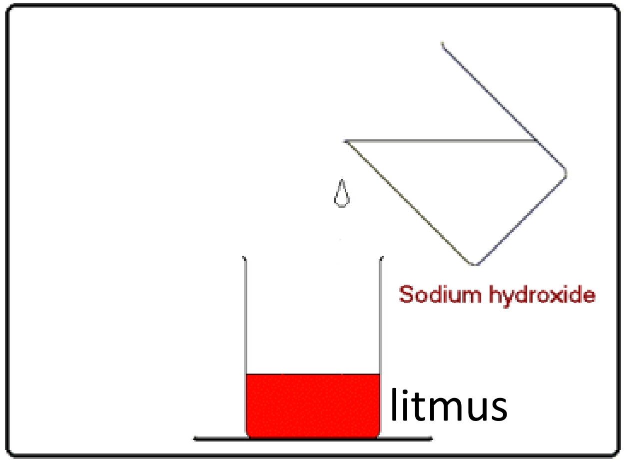
Weak conjugated acids and bases in aqueous solution are not subject to hydrolysis (do not react with water)

(1) Salts of strong acids and strong bases

$$NaOH + HCl \rightarrow NaCl + H_2O$$

sodium chloride does not hydrolyze $NaCl + H_2O \rightarrow /$

$$NaCl \rightarrow Na^+ + Cl^-$$



Na^+ ion comes from the strong base NaOH → it is a weak conjugate acid → it does not undergo hydrolysis

Cl^- the ion comes from the strong acid HCl → it is a weak conjugate base → it does not undergo hydrolysis

pH = 7

Neutral salts of strong acids and strong bases do not hydrolyze and their aqueous solutions react neutrally.

$CaSO_4$, $BaCl_2$, $CaCl_2$, KNO_3, $MgBr_2$, NaI

NaCl

Acid salts of strong acids and strong bases

$$NaHSO_4 \rightarrow Na^+ + HSO_4^-$$

Na^+ the ion comes from the strong base NaOH → it is a weak conjugate acid → it is not subject to hydrolysis

HSO_4^- ion comes from a strong acid **H_2SO_4** → it is a weak conjugate base → not subject to hydrolysis

BUT...

$$HSO_4^- \rightarrow H^+ + SO_4^{2-}$$

pH < 7

the solution reacts acidic

Acidic salts of strong acids and strong bases are not subject to hydrolysis, but their aqueous solutions react acidic due to dissociation.

$NaHSO_4$, $Ca(HSO_4)_2$, $Mg(HSO_4)_2$ but also NaH_2PO_4

$$NaH_2PO_4 \rightarrow Na^+ + H_2PO_4^-$$

NaH_2PO_4 is a salt of a weak acid and a strong base, which is not subject to hydrolysis and whose aqueous solution reacts acidic (pH < 7)

Base salts of strong acids and strong bases

$$Ca(OH)Cl \rightarrow Ca(OH)^+ + Cl^-$$

$Ca(OH)^+$ ion comes from a strong base **$Ca(OH)_2$** → it is a weak conjugate acid → it is not subject to hydrolysis
Cl^- the ion comes from the strong acid HCl → it is a weak conjugate base → it does not hydrolyze

BUT... $$Ca(OH)^+ \rightarrow Ca^{2+} + OH^-$$

pH > 7 the solution reacts basic

Base salts of strong acids and strong bases are not subject to hydrolysis, but their aqueous solutions react basicly due to dissociation.

$Mg(OH)Cl$, $Ca(OH)NO_3$, $Ba(OH)NO_3$

(2) Salts of strong acids and weak bases

neutralization

$$NH_4OH + HCl \rightleftharpoons NH_4Cl + H_2O$$

hydrolysis

Ammonium chloride can hydrolyze :

$$NH_4Cl + H_2O \rightleftharpoons NH_4OH + HCl$$

hydrolysis equation in molecular form

$$NH_4Cl \rightarrow NH_4^+ + Cl^-$$

NH_4^+ ion comes from a weak base **NH_4Cl** → it is a strong conjugate acid → it can hydrolyze
Cl^- ion comes from a strong acid **HCl** → it is a weak conjugate base → not subject to hydrolysis

$$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$$

acid 1 base 2 base 1 acid 2

hydrolysis equation in ionic form

$$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$$

pH < 7

NH_4^+ ion is a strong conjugate acid and donates a proton to water, which acts as a base

Due to the hydrolysis reaction, the aqueous solution of ammonium chloride reacts acidic.

Salts of strong acids and weak bases are subject to hydrolysis, whereby their aqueous solutions react acidic due to hydrolysis.

Applying the law of conservation of mass:

$$K = \frac{[NH_3][H_3O^+]}{[H_2O][NH_4^+]}$$

$$\underbrace{K[H_2O]}_{\text{constant } K_h} = \frac{[NH_3][H_3O^+]}{[NH_4^+]}$$

$$K_h = \frac{[NH_3][H_3O^+]}{[NH_4^+]}$$

K_h – hydrolysis constant

pH in salt solution where the cation hydrolyzes

$$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$$

$$K_h = \frac{[NH_3][H_3O^+]}{[NH_4^+]}$$

$$[H_3O^+] = [NH_3]$$

$$[NH_4^+] = c_s$$

$$K_h = \frac{[H_3O^+]^2}{c_s}$$

$$[H_3O^+] = \sqrt{K_h \cdot c_s}$$

$$[H_3O^+] = \sqrt{\frac{K_w}{K_b} \cdot c_s}$$

equation for calculating pH

Base salts of strong acids and weak bases

$$Zn(OH)Cl \rightarrow Zn(OH)^+ + Cl^-$$

zinc-hydroxychloride

pH < 7

$Zn(OH)^+$ ion comes from a weak base **$Zn(OH)_2$** → it is a strong conjugate acid → undergoes hydrolysis

$$[Zn(OH)(H_2O)_3]^+ + H_2O \rightleftharpoons [Zn(OH)_2(H_2O)_2] + H_3O^+$$

Base salts of strong acids and weak bases are subject to hydrolysis, whereby their aqueous solutions react acidic due to hydrolysis.

(3) Salts of weak acids and strong bases

neutralization

$$CH_3COOH + NaOH \rightleftharpoons CH_3COONa + H_2O$$

hydrolysis

Sodium-acetate undergoes hydrolysis:

$$CH_3COONa + H_2O \rightleftharpoons CH_3COOH + NaOH$$

hydrolysis equation in molecular form

$$CH_3COONa \rightarrow Na^+ + CH_3COO^-$$

Na^+ ion comes from the strong base NaOH → it is a weak conjugate acid → it does not undergo hydrolysis

CH_3COO^- ion comes from a weak acid **CH_3COOH** → is a strong conjugate base → undergoes hydrolysis

$$CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$$

base 1 acid 2 acid 1 base 2

hydrolysis equation in ionic form

$$CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$$

pH > 7

CH_3COO^- ion is a strong conjugate base and accepts a proton from water, which acts as an acid.

Due to the hydrolysis reaction, the sodium acetate aqueous solution reacts basic.

Salts of weak acids and strong bases are subject to hydrolysis, and their aqueous solutions react basic due to hydrolysis.

pH in a salt solution where the anion hydrolyzes

$$CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$$

$$K_h = \frac{[CH_3COOH][OH^-]}{[CH_3COO^-]}$$

$$[OH^-] = [CH_3COOH]$$

$$[CH_3COO^-] = c_s$$

$$K_h = \frac{[OH^-]^2}{c_s}$$

$$[OH^-] = \sqrt{K_h \cdot c_s} \Rightarrow [OH^-] = \sqrt{\frac{K_w}{K_a} \cdot c_s}$$

Acid salts of weak acids and strong bases

$$NaHCO_3 \rightarrow Na^+ + HCO_3^-$$

baking soda

$NaHCO_3$

sodium hydrogencarbonate

bicarbonate of soda

HCO_3^- ion comes from a weak acid **H_2CO_3** → is a strong conjugate base → undergoes hydrolysis

$$HCO_3^- + H_2O \rightleftharpoons H_2CO_3 + OH^-$$

pH > 7

Acidic salts of weak acids and strong bases are subject to hydrolysis, whereby their aqueous solutions react as bases due to hydrolysis.

(4) Salts of weak acids and weak bases

Salts of weak acids and weak bases can hydrolyze, whereby the pH value of their aqueous solutions depends on K_a **and** K_b

neutral medium — $K_a = K_b$, pH = 7

acid medium — $K_a > K_b$, pH < 7

base medium — $K_a < K_b$, pH > 7

$$K_a = K_b$$

Aqueous solution of ammonium acetate **(CH_3COONH_4)** reacts neutrally, regardless of concentration.

$K_a(CH_3COOH) = 1{,}8\cdot10^{-5}$

$K_b(NH_3) = 1{,}8\cdot10^{-5}$

neutral reaction

$K_a > K_b$

Aqueous solution of ammonium formiate **($HCOONH_4$)** reacts acidic

$K_a(HCOOH) = 1{,}6 \cdot 10^{-4}$

$K_b(NH_3) = 1{,}8 \cdot 10^{-5}$

acid reaction

$K_a < K_b$

Aqueous solution of ammonium cyanide **(NH_4CN)** reacts basicly

$K_a(HCN) = 7{,}9 \cdot 10^{-10}$

$K_b(NH_3) = 1{,}8 \cdot 10^{-5}$

base reaction

BUFFERS

- A buffer is an acid or a base aqueous solution consisting of a mixture of a weak acid and its conjugate base or a mixture of a weak base and its conjugate acid.

- WHAT IS A BUFFER COMPOSED OF?

- Buffers are mixtures usually composed of

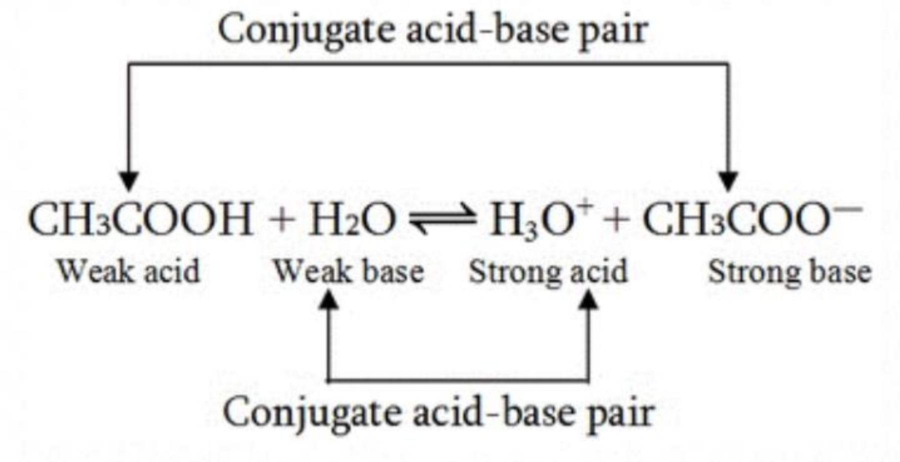
- **a weak acid and its salt** (acetic acid/sodium acetate) CH_3COOH/ CH_3COO^-
- **a weak base and its salt** (ammonium hydroxide/ammonium chloride)

- Buffer is a solution that **can resist pH change** [in the concentration of hydronium (H_3O^+) and hydroxide (OH^-) ions] upon the addition of an acidic or basic components.

- Resists changes, thus maintaining a constant pH value.

- The basic property of buffers is to regulate the acidity of the solution (pH value) and keep it constant.

Dissociation of acetic acid $CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H^+$



Dissociation of sodium acetate

$$CH_3COONa \rightarrow CH_3COO^- + Na^+$$

Hydrolysis of acetate ions

$$CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$$

Hydronium ion concentration is calculated from the expression:

Henderson–Hasselbalch equation

$$[H_3O^+] = K_a \frac{[HA]}{[A^-]}$$

n numbers of moles of acid and its conjugate bases.

Logarithmizing the above equation yields the following expression :

$$pH = pK_a + \log \frac{[A^-]}{[HA]}$$

[HA] – concentration of acid

[A-] – concentration of conjugated base

$$pK_a + pK_b = 14$$

Problem

Calculate the pH of a buffer solution containing 0.60 *M* NH_3 and 0.35 *M* NH_4Cl. The pK_b of ammonia is 4.75.
The first step is to determine the pK_a so that we can use it in the Henderson–Hasselbalch equation:

$pK_a + pK_b = 14$
$pK_a = 14 – pK_b = 14 – 4.75 = 9.25$

Because the concentrations of the buffer components are significantly higher than the K_b of ammonia, all we need to do, at this point, is plugging the numbers in the equation:

$$\mathrm{pH} = \mathrm{p}K_\mathrm{a} + \log\frac{[\mathrm{A}^-]}{[\mathrm{HA}]}$$

$$\mathrm{pH} = 9.25 + \log\frac{[0.60]}{[0.35]} = 9.5$$

$$pH + pOH = 14$$

- **Buffer capacity -** the number of moles of acid or base that must be added to one liter (1L) of the buffer solution in order to lower or raise the pH by one unit.

- The most important buffers in the human body are: phosphate, bicarbonate (hydrocarbon), protein and hemoglobin, and the organs involved in maintaining pH constancy are: blood, liver, kidneys and lungs. Maintaining a normal pH value in the body is very important, which is made possible by buffers.

- **The pH-value of blood ranges between 7.35 and 7.45, depending on whether it is arterial or venous blood.**

- **Blood** in the human body is buffered at pH 7.35-7.45.

- Buffers job is to maintain blood pH as close as possible to 7.4!
- Buffers are crucial because any changes in blood pH can lead to death!

- **What is the pH of a buffer solution that has 0.08 M CH_3COONa and 0.10 M CH_3COOH? (K_a = 1.76 x 10^{-5})** *(answer: pH = 4.65)*

- **Which of the following buffers have greater capacity? 0.10 M Tris buffer vs. 0.01 M Tris buffer.**

(Answer: We learned that the higher the concentration,

the greater the buffer capacity!

So, the 0.10 M Tris buffer will have a greater buffer capacity)

- Phosphate buffer ($H_2PO_4^-/HPO_4^{2-}$) it represents 1% of the buffer capacity of blood, and it consists of dihydrogen phosphate $H_2PO_4^-$ and hydrogen phosphate HPO_4^{2-}:

$$HPO_4^{2-} + H^+ \rightleftharpoons H_2PO_4^-$$

$$H_2PO_4^- + OH^- \rightleftharpoons H_2O + HPO_4^{2-}$$

Bicarbonate buffer (H_2CO_3/HCO_3^-) it is a mixture of bicarbonate and carbonic acid in a ratio of 1:20 and is the most important inorganic blood buffer, which makes up 5% of the buffer system.

Protein buffer (protein/proteinate) makes up 93% of the blood's buffer capacity, of which 80% is hemoglobin, and 13% is other serum proteins.

Hemoglobin has the highest buffering capacity in human blood (up to 80%). The hemoglobin system in the blood consists of free, reduced and oxidized hemoglobin, as well as carboxyhemoglobin.

- In order to change the pH value of 100 cm^3 of "normal" blood from 7.35 to 7.00, it is necessary to add about 25 cm^3 of 0.05 M HCl.

- Measurement of changes in the pH value of water (above) and buffer (below) using a *pH meter*.

Periodic Table of the Elements

- **Periodic Table of the Elements** (PSE) was first devised by the Russian chemist Dmitri Mendeleev in 1869.
- The similarity of electronic configurations in a group conditions the similarity in the properties of the elements.
- **Law of Periodicity**: "The chemical and physical properties of elements are a periodic function of their relative atomic masses."

What changes periodically in PSE?

Atomic and ionic radius   Atomic volume
Melting point
Boiling point
Density
Ionization energy
Electron affinity
(Non)metallic character

BIO ELEMENT

BIOGENIC ELEMENT

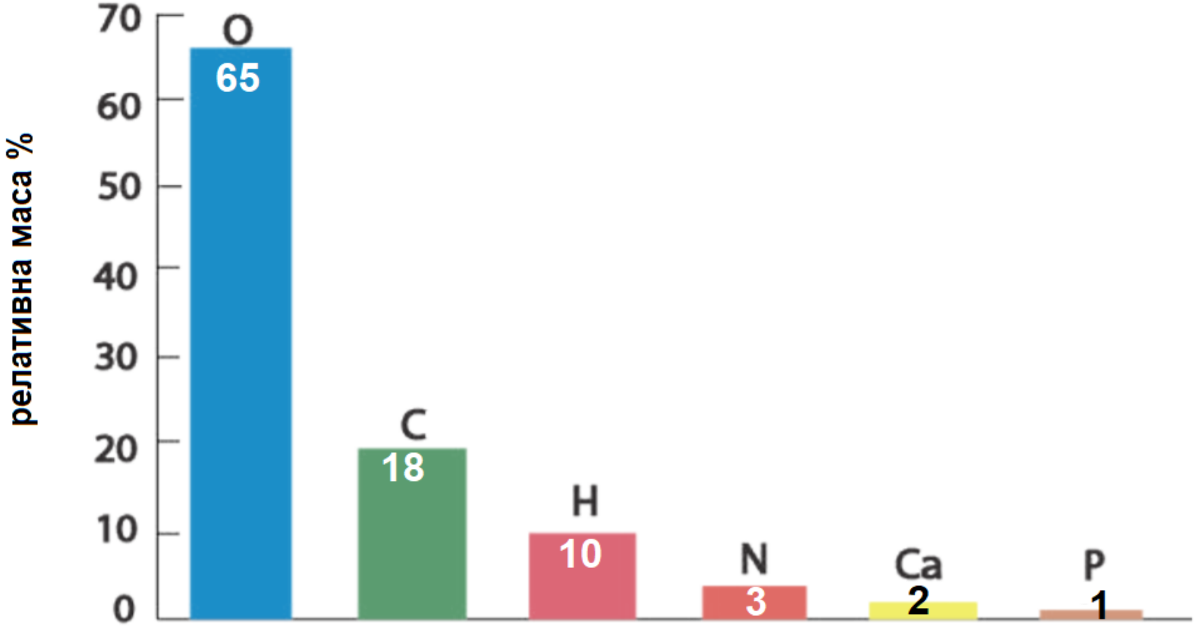
- **Bioelements** are chemical elements found in compounds that make up living organism.

- **The most common bioelements** in the human body are:

oxygen (65%), carbon (18%), hydrogen (10%), nitrogen (3%), calcium (2%) and phosphorus (1%).

According to the concentration (%) in which they are present in the human body, biogenic elements are divided into:

1. **macroelements** (Greek macro=many) whose amount in the body is 0.040% or more
2. **microelements** (micro = small, tiny) whose amount in the body is up to 0.039%
3. **ultramicroelements** whose quantity is in traces.



K: 0.35%, S: 0.25%, Cl: 0.15%, Na 0.15%,
Mg 0.05 %, Fe: 0.0045%,
Cu, Mn, Zn, J (traces)

Properties of metals

Good conductors

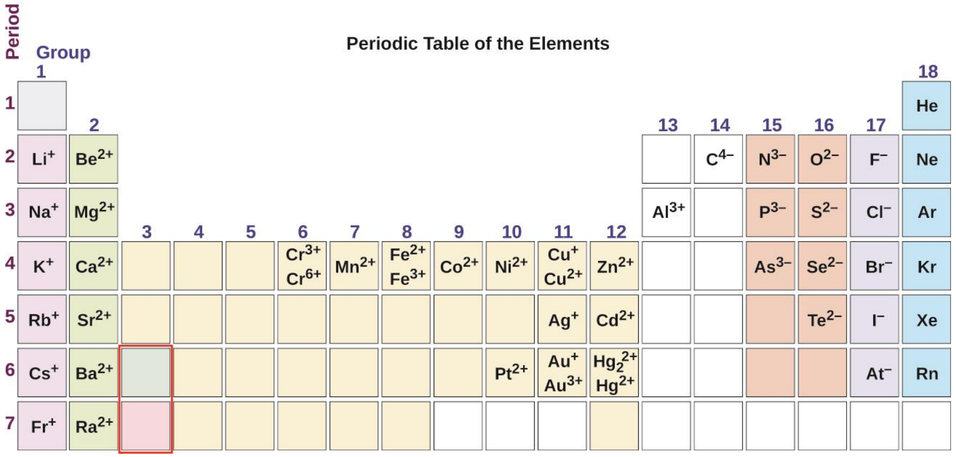
- They have a specific shine and are mostly silvery in color
- Malleability - they can be forged, i.e. they draw out in sheets
- Elasticity – they can be drawn into strings
- Good conductors of heat and electricity
- They are mostly in a solid aggregate state at room temperature

(except for mercury, which is liquid and freezes at -39°C)

- They have low ionization energy values and relatively easily build positive ions
- They release electrons in chemical reactions

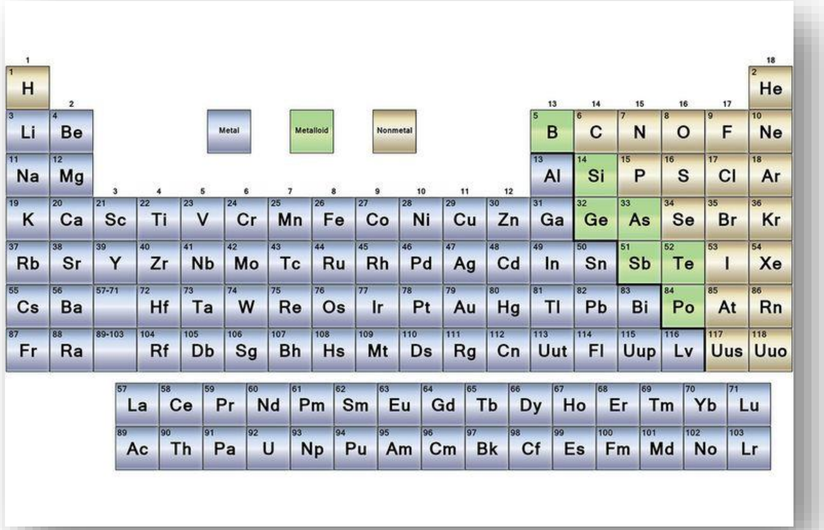
Main group metals shed electrons to achieve a stable noble gas configuration.

Transition metals can exist in multiple ionic states - there is no connection to a stable noble gas configuration.



Nonmetals - Properties of nonmetals

- Seven nonmetals exist as diatomic molecules, of which:
  - a) five as gases **(H_2, N_2, O_2, F_2, Cl_2)**
  - b) one is a liquid **(Br_2)**
  - c) one is a solid **(I_2)**
- Other nonmetals exist as solids, very hard (diamond) or soft (sulfur).
- They have significantly higher ionization energy and electron affinity - they easily build negative anions.



Metalloids - properties of metalloids

- Properties that lie between the properties of non-metals and metals
- Semiconductors of electricity

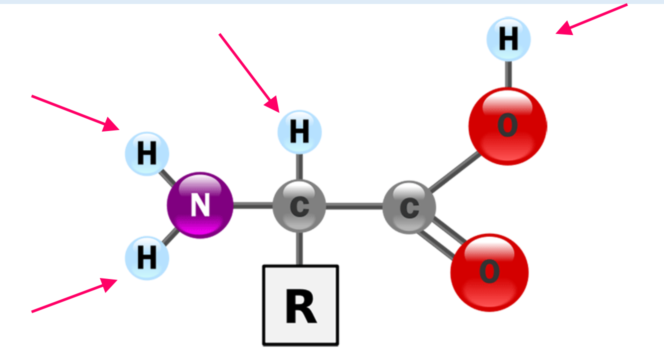
Silicon

Hydrogen (H)

Hydrogen (H) is a colorless, tasteless and odorless gas, which practically does not dissolve in water because its molecules are non-polar.

It is found as a constituent of a large number of organic and inorganic molecules, water, ammonia, amino acids, proteins, carbohydrates, etc.

Hydrogen makes up 9-10% of body mass.



Amino acids

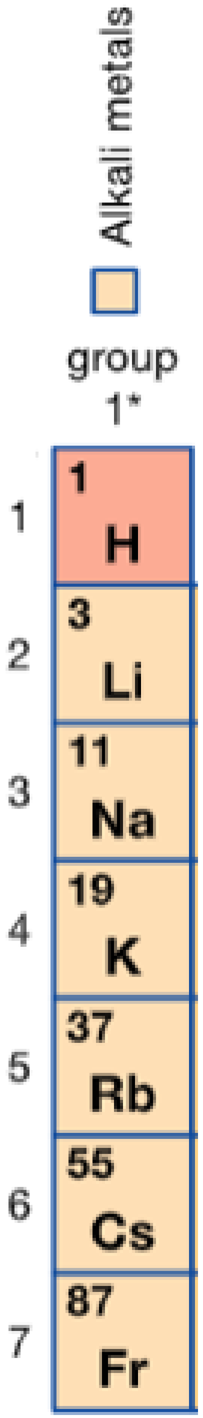
Stomach acid is a digestive fluid formed in the stomach that has a **pH of 1.5 to 3.5**.

Stomach acid consists of hydrochloric acid (about 0.5%), and large amounts of potassium chloride and sodium chloride. This acid plays a key role in protein digestion.

It has antimicrobial effects and protects against leaky gut syndrome, protects against *Candida,* supports skin health and helps with nutrient absorption (especially protein and vitamin B12).

Baking soda (sodium bicarbonate $NaHCO_3$)

$$NaHCO_3 + HCl = NaCl + H_2O + CO_2$$



ELEMENTS OF I GROUP OF THE PERIODIC SYSTEM (ALKALINE METALS)

The first group of the periodic system includes the following elements: lithium (Li), sodium (Na), potassium (K), rubidium (Rb), cesium (Cs) and francium (Fr).

Lithium (Li, Greek lithos — stone) is the lightest of all known metals, it is silvery in color, and due to its high reactivity, it is not found in the elemental state in nature. It was also found in the ashes of many plants, but also in milk and blood.

Lithium deficiency affects the endocrine system, fertility and causes mental illnesses. Ceramic crowns made of lithium disilicate are used in dentistry.

Sodium is a soft (can be cut with metal), silver-white, highly reactive alkali metal.

The most important sodium compounds are: sodium chloride, sodium nitrate (Chilean saltpetre), sodium carbonate, sodium bicarbonate (baking soda).

Sodium cations are among the most important **intracellular cations**, and are necessary for the maintenance of the cell membrane.

- The sodium content in the body is about 0.08%. It is the main extracellular cation (sodium pump).

Potassium is a soft silver-shiny highly reactive alkali metal. It is the main intracellular cation (98%).

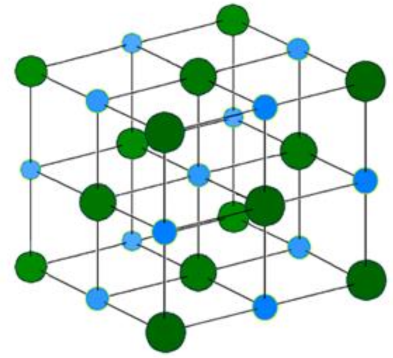
It is important in muscle contraction, normal functioning of the heart, transmission of nerve impulses, activation of enzymes. K+ cations color the flame in a pinkish-purple color. The most important compounds of potassium are: potassium oxide (K_2O), potassium peroxide (K_2O_2), potassium superoxide (KO_2), potassium hydroxide (KOH), potassium permanganate ($KMnO_4$) (and other salts). Potassium hydroxide is, like sodium hydroxide, a strong base.

- The sodium-potassium pump (Na-K pump) is a type of active transport of ions through the cell membrane that move from an environment with a lower concentration to an environment with a higher concentration, even though there is more sodium outside the cell (in the extracellular environment) than inside it, and potassium vice versa. The process takes place with the help of carrier molecules and with the consumption of energy.

Sodium - extracellular cation

Potassium - intracellular cation

Sodium chloride (NaCl) or table salt is an ionic compound used as a seasoning, and can be obtained from seawater or salt mines.

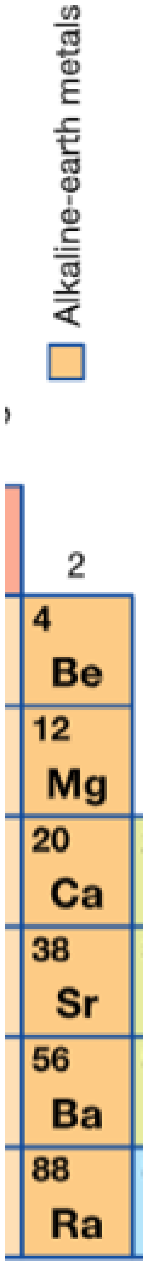


Crystal structure of sodium chloride

Salinity is one of the most important properties of seawater and represents the amount of salt dissolved in one kilogram of water, expressed in parts per million. A salinity of one per thousand means that one gram of salt is dissolved in a kilogram of water.

Sodium nitrate ($NaNO_3$) is a white powdery substance that is very soluble in water. Dissociation of sodium nitrate produces nitrate anion (NO_3^-), which is useful in the production of fertilizers (nitrogen fertilizers), food preservatives (especially meat), and as solid rocket fuel. Sodium nitrate (E251) and sodium nitrite ($NaNO_2$, E250) are food additives, which are used as preservatives and color fixing agents in meat products.

ELEMENTS OF II GROUP OF THE PERIODIC SYSTEM (ALKALINE EARTH METALS)



The second group of the periodic table includes the following elements: **beryllium, magnesium, calcium, strontium, barium and radium.**

Magnesium (Mg) is a solid, silvery metal that oxidizes very easily in air.

Mg content in the body is 0.27%

Magnesium is important in energy processes, it forms complexes with **ATP** ($MgATP^{2-}$), in protein biosynthesis, ribosome stability.

The most important magnesium compounds are: magnesium oxide MgO, magnesium hydroxide $Mg(OH)_2$ and its carbonates.

Aqueous solutions Mg^{2+} taste bitter.

Calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) are included in the composition of the rocks of the mountain ranges.

The hardness of water is determined by the amount of calcium and magnesium ions in it.

- **Calcium (Ca)** is a shiny, silvery, soft and light metal. Its content in the body is 1.4%.
- Mainly occurs in bones and teeth) and mostly in the form of hydroxyapatite

$Ca_{10}(PO_4)_6(OH)_2$.

Lack of calcium and vitamin D in bones causes rickets.

- Important calcium compounds include: calcium oxide, CaO (quick or quicklime) which with water gives calcium hydroxide, $Ca(OH)_2$ (slaked lime), chalk (calcite mineral ($CaCO_3$),

limestone (such as calcite or marble) and gypsum (calcium sulfate dihydrate,

$CaSO_4 \cdot 2H_2O$).

- Alkaline earth carbonates and sulfates are insoluble in water.
- **Barium (Ba)** is an alkaline earth metal that occurs in the form of barium sulfate

(baryta) is used as a contrast medium in radiology (changes x-ray absorption

in the organ, gastro-intestinal tract and allows display on x-ray film or monitor).

Elements of the XIII and XIV groups of the PTE

Elements of the 13th group of PSE include:
boron (B), aluminum (Al), gallium (Ga), indium (In), thallium (Tl) and the last discovered element nihonium (Nh).

Boron is a metalloid,
all other elements are metals.

Boron is an important biogenic element found in bones, muscles, liver, teeth and thyroid.
One of the most important boron compounds is **boric acid (H_3BO_3)** which builds borate salts that serve as cleaning agents.
Boric acid is a very weak acid and can be used as an insecticide and antiseptic **(Acidi borici, 3% solution is used to wash the eyes).**

Aluminum has little biological activity in the body.

Elements of the 14th PSE group include: carbon (C), silicon (Si), germanium (Ge), tin (Sn) and lead (Pb). In this group there is also an element with serial number 114, called flerovium (Fl), which is radioactive.

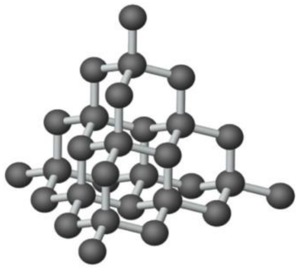
Carbon (C)

It is the second most abundant in the human body.

All living tissues are composed of organic compounds of carbon.

Allotropic modifications of carbon

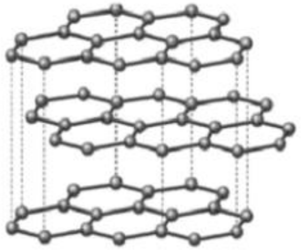
Diamond



carbon atoms make sp^3-hybridization with a tetrahedral spatial arrangement

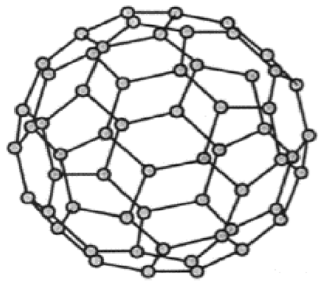
It is hard and does not conduct electricity

Graphite



sp^2-hybridization and the three hybrids lie in one plane.
Very soft and a conductor of electricity

Fullerene



discovered in 1991. and consists of 60 or 70 sp^2 hybridized C atoms)

Carbon monoxide (CO) is a colorless and odorless gas. It acts as a strong reducing agent. Cars are among the biggest emitters of this polluting gas.

It is **very toxic,** because it has a **strong affinity for binding with hemoglobin** in the blood in a similar way as oxygen and causes general hypoxia in the body (lack of oxygen).

Carbonic (carbonic) acid (H_2CO_3) is a metastable product and it is dissolved in water CO_2

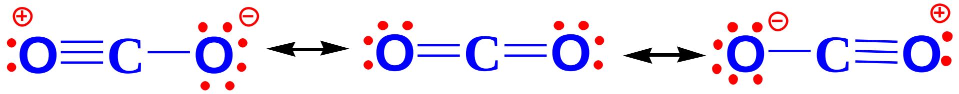
it forms two types of salts: **carbonates and bicarbonates**. **Na**$_2CO_3$ **Na**HCO_3

$$CO_2 + H_2O \leftrightarrows H_2CO_3$$

Oxidation state **+2:**

- CO_2 carbon(IV)-oxide (carbon dioxide)
- H_2CO_3 carbonic acid
- HCO_3^- hydrogen carbonate
- CO_3^{2-} carbonates

Carbon dioxide (CO_2) is a colorless, odorless gas.
It is released by most living things **in the process of respiration**, and for plants it is necessary for the process of photosynthesis. Carbon dioxide makes up about 0.038% of the Earth's atmosphere.



CO_2: - colorless and odorless gas
- not poisonous
- 0.04% in air
- heavier than air
- dissolved in water

Obtaining **:** $CaCO_3 + 2\,HCl \longrightarrow CaCl_2 + CO_2 + H_2O$

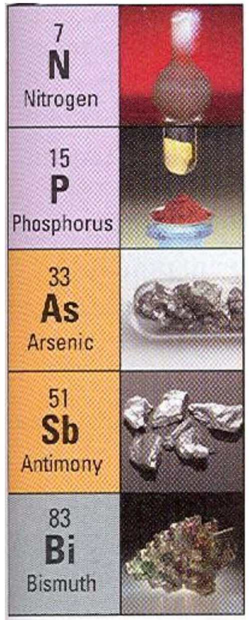
Alcoholic fermentation $C_6H_{12}O_6 \longrightarrow 2\,C_2H_5OH + 2\,CO_2$

By thermal decomposition **$CaCO_3$:** $CaCO_3 \rightleftharpoons CaO + CO_2$

- for the production of carbonated drinks
- against fire
- dry ice

ELEMENTS OF XIV GROUP OF THE PERIODIC SYSTEM

nitrogen (N), phosphorus (P), arsenic (As), antimony (Sb) and bismuth (Bi), as well as the last discovered element from this group, muscovium (Mc).



nonmetals (acidic oxides)

metalloids (amphoteric oxides)

metal (base oxides)

Nitrogen

Nitrogen (N, lat. nitrogenium) is widespread in nature as molecular dinitrogen N_2 ($N \equiv N$)

Nitrogen is the most abundant element in **air**.

It is found in Chilean saltpeter ($NaNO_3$),

It is represented in **amino acids and proteins** of plant and animal origin, as well as **in nucleic acids**.

nitrogen cycle

Nitrogen

$_7N$ $1s^2$ $2s^22p^3$

Distribution:
- in the air about 78%
- in Chilean saltpeter ($NaNO_3$)
- iogenic element

Features:
- colorless and odorless gas, does not burn, does not support burning
- inert gas, diamagnetic
- the cheapest and most accessible inert gas

Laboratory production of nitrogen: - by thermal decomposition ammonium nitrite

$$\overset{-3}{N}H_4\overset{+3}{N}O_2 \longrightarrow \overset{0}{N_2} + 2\,H_2O$$

Nitric (nitric) acid is one of the most important industrial acids and is produced in large quantities from ammonia.
Nitric acid anhydride is N_2O_5.

$$N_2O_5 + H_2O \rightarrow 2\,HNO_3$$

Concentrated nitric acid belongs to **toxic mineral acids**.

The use
In a liquid aggregate state for rapid cooling in industry, food production, medicine and veterinary medicine, scientific and technical research...

Nitrogen makes up 3.1% of the total weight and 11% of the dry weight of the human body.
It is found in amino acids, proteins, nucleic acids.

Ammonia (NH_3) is a colorless gas with a sharp unpleasant smell. Haber-Bosch procedure :

$$3H_2 + N_2 \leftrightarrows 2NH_3$$

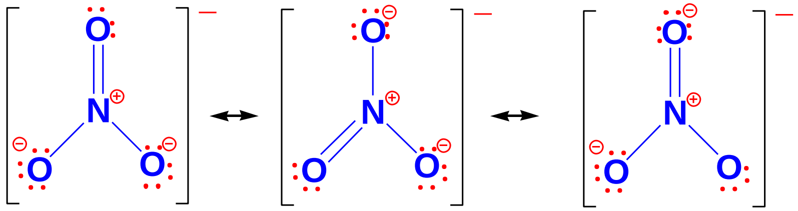
Nitric oxide or nitrous oxide (NO) is used in neonatology as a natural vasodilator present in the vascular endothelium of the whole organism.

N_2O

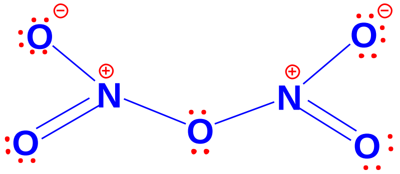
Nitrogen suboxide (N_2O) is a colorless, sweet-tasting gas used in medicine and dentistry as an anesthetic and analgesic because it is non-toxic. It is also used in the food and pharmaceutical industry. Also called "laughing gas"

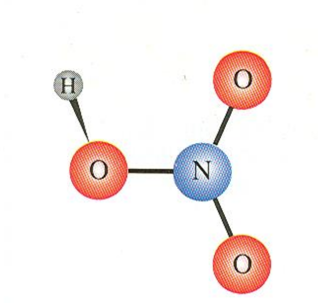
Nitric acid HNO_3

Strong acid
Colorless liquid
Salts are nitrates
dissolves all metals except Au, Pt, Ir and Rh



$$N_2O_5 + H_2O \longrightarrow 2\ HNO_3$$





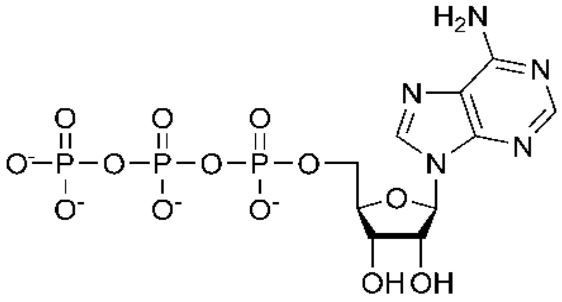
Cryotherapy (cryosurgery) is a method of controlled tissue destruction by freezing with liquid cryogens (cooled liquid oxidizing gas under pressure, eg liquid nitrogen). This method is used in dermatology.

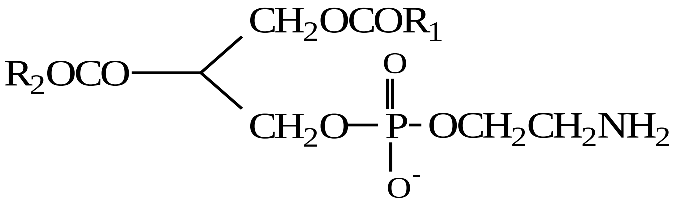
Phosphorus

It is found in nature in the form of **phosphorite** $Ca_3(PO_4)_2$ and **apatite** ($Ca_5(PO_4)_3F$, $Ca_5(PO_4)_3Cl$, $Ca_5(PO_4)_3OH$), and **in the body it is present (1%) in bones and teeth** $Ca_3(PO_4)_2$ (60%) and other important molecules (biogenic element), such as **adenosine triphosphate (ATP), phospholipids**, is an integral part of **nucleic acids**.

- There is no free elemental phosphorus in nature

ATP





phospholipids

Allatrope modifications of phosphorus: white, red and black.

White phosphorus (P4) is an unstable allotropic modification, which is stored under water.
It glows in the dark (phosphorescence).
It is a strong poison (the lethal dose for humans is 0.1 g), and it causes wounds on the skin that are difficult to heal.

Phosphoric acid is one of the most important compounds of phosphorus.
It is a weak tribasic acid that dissociates in three stages.

$$H_3PO_4 + H_2O \rightleftarrows H_2PO_4^- + H_3O^+ \quad k_1 = 1{,}1 \times 10^{-2}\ mol/dm^3$$
$$H_2PO_4^- + H_2O \rightleftarrows HPO_4^{2-} + H_3O^+ \quad k_2 = 1{,}2 \times 10^{-7}\ mol/dm^3$$
$$HPO_4^{2-} + H_2O \rightleftarrows PO_4^{3-} + H_3O^+ \quad k_3 = 1{,}8 \times 10^{-12}\ mol/dm^3$$

An aqueous solution of dihydrogen phosphate reacts weakly acidic.

$$H_2PO_4^- + H_2O \rightleftarrows HPO_4^{2-} + H_3O^+ \quad k_2 = 1{,}2 \times 10^{-7}\ mol/dm^3$$

Arsenic (As) is a metalloid.

The most famous compound of arsenic is extremely toxic **arsenic trioxide As_2O_3** which is used to destroy mice and rats (mouse killer).

It is also associated with the **Spanish Borgia family**, which was synonymous with **poisoners.**

Trivalent arsenic is classified as carcinogenic to humans.

However, some arsenic compounds such as melarsoprol are used for African trypanosomiasis or sleeping sickness.

If you like life, never go to lunch at Borgia's.

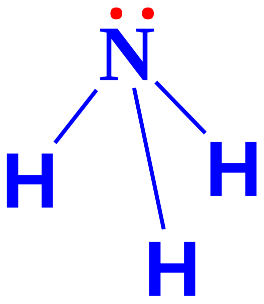
Hydrides

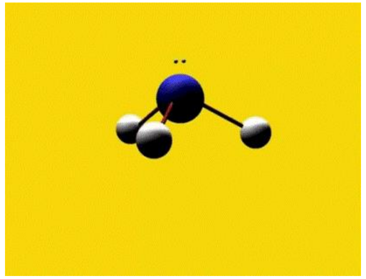
Oxidation state-3:

AH_3 – hydrides, gases, pyramidal geometry

NH_3	**ammonia**
PH_3	**phosphine**
AsH_3	**arsine**
SbH_3	**stibin**
BiH_3	**bismuthine**

stability decreases
the basicity decreases
the reducing power increases
toxicity increases





Ammonia is used to obtain nitric acid, ammonium salts, nitrates (artificial fertilizers), in the oil industry.

Ammonia poisoning is a common disease of fish in aquariums

Phosphoric acid is a weak tribasic acid:

$$H_3PO_4 + H_2O \rightleftharpoons H_2PO_4^- + H_3O^+ \qquad K_1 = 1{,}1 \times 10^{-2}\ mol/dm^3$$

$$H_2PO_4^- + H_2O \rightleftharpoons HPO_4^{2-} + H_3O^+ \qquad K_2 = 1{,}2 \times 10^{-7}\ mol/dm^3$$

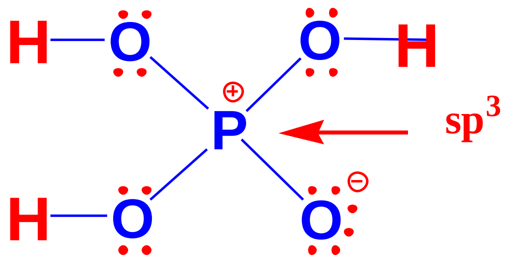
$$HPO_4^{2-} + H_2O \rightleftharpoons PO_4^{3-} + H_3O^+ \qquad K_3 = 1{,}8 \times 10^{-12}\ mol/dm^3$$

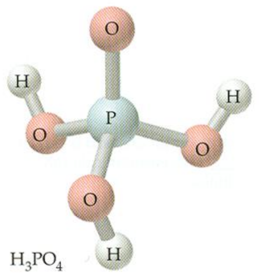
An aqueous solution of dihydrogen phosphate reacts weakly acidic

$$H_2PO_4^- + H_2O \rightleftharpoons HPO_4^{2-} + H_3O^+ \qquad K_2 = 1{,}2 \times 10^{-7}\ mol/dm^3$$

Aqueous solution of hydrogen phosphate reacts weakly basic

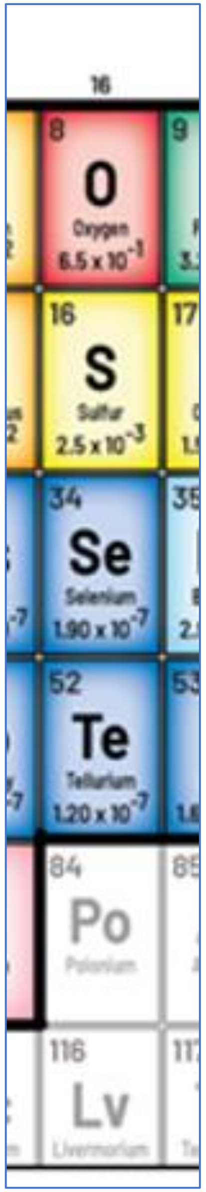
$$HPO_4^- + H_2O \rightleftharpoons H_2PO_4^- + OH^-$$





dihydrogen phosphates - soluble in water
hydrogen phosphates and phosphates - soluble only of alkali metals

CHALCOGENE ELEMENTS (XVI GROUP PSE)



halkos genesis = "builds ores".
non-metals: *oxygen and sulfur (S),*
metalloids *selenium (Se) and tellurium (Te) and*
metal *polonium (Po).*

The last discovered element in this group, livermorium (Lv), also belongs to this group.

All elements of the 16th group form compounds with hydrogen: water (H_2O), hydrogen sulfide (H_2S), hydrogen selenium (H_2Se) and hydrogen tellurium (H_2Te).

Oxygen O_2

(lat. oxygenium) is a colorless gas without odor and taste. It is slightly soluble in water.

In its elemental form, oxygen mainly occurs as
nonpolar paramagnetic diatomic molecule of the formula O_2.
Oxygen is the most abundant element on Earth,
and in clean air it is represented by about 20%.

Oxygen is created by plants in the process of photosynthesis, and is necessary for combustion and corrosion.

$$nH_2O + nCO_2 \rightarrow C_n(H_2O)_n + nO_2$$

$$6H_2O + 6CO_2 \rightarrow C_6H_{12}O_6 + 6O_2$$

Oxygen makes up 62% of the total human body weight and 9.3% of dry weight.
It is a constituent of **proteins, carbohydrates, lipids** and many other biomolecules.
It is needed **in the process of breathing**, because it binds to hemoglobin, which transports it in the blood. Oxygen reacts with most elements.

Red blood cells

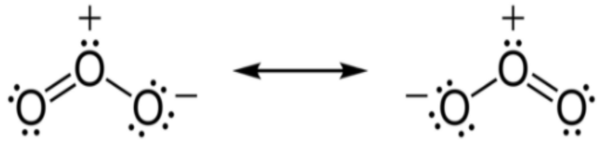
Oxygen O_2

Hemoglobin

Iron

Oxygen can have the following oxidation states: -2, -1 and -1/2.

Important oxygen compounds are: oxides and peroxides. The chemical reaction of combining oxygen with other substances is called **oxidation.**



O_3 is **ozone**
A highly reactive allotropic form of oxygen with three oxygen atoms. It is a bluish colored gas.

Ozone is the strongest oxidizing agent after fluorine, it destroys bacteria, bleaches organic colors and reacts with unsaturated organic compounds, building ozonides.

Oxygen, sulfur and selenium are biogenic elements.

Oxides are compounds of oxygen with other elements in which its oxidation state is -2. They are divided into acidic, basic, amphoteric and neutral.

Acidic oxides (such as sulfur(IV)-oxide, i.e. sulfur-dioxide) with water give acidic reactions, neutralize bases and dissolve in bases.

$$SO_{3(g)} + H_2O_{(l)} \rightarrow H^+ + HSO_4^-$$

$$SO_{3(g)} + NaOH_{(aq)} \rightarrow Na_2SO_{4(aq)} + H_2O_{(l)}$$

Acidic oxides are: CO_2, SO_2, SO_3, NO_2, N_2O_5, N_2O_3, P_4O_{10}.

Basic oxides with water give bases, neutralize acids and dissolve in acids.

$$Na_2O + H_2O \rightarrow 2NaOH$$

$$CaO + H_2O \rightarrow Ca(OH)_2$$

Amphoteric oxides neutralize both acids and bases and dissolve in them.

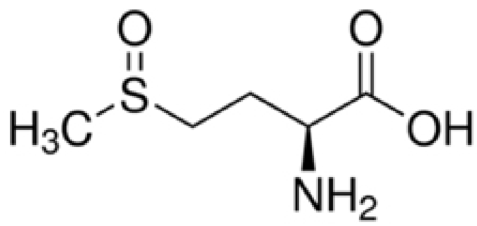
$$ZnO + 2H^+ \rightarrow Zn^{2+} + H_2O$$

$$ZnO + 2OH^- + H_2O \rightarrow [Zn(OH)_4]^{2-}$$

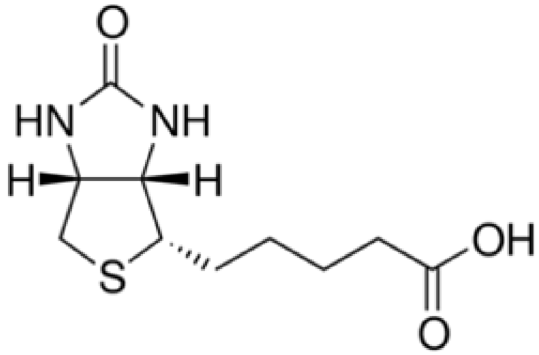
Amphoteric oxides are: zinc oxide (ZnO), chromium(III) oxide, (Cr_2O_3) and manganese(IV)-oxide (MnO_2).

Neutral oxides do not react with water, do not dissolve in acids or bases, and do not react with acids or bases. Neutral oxides are: carbon(II)-oxide (CO) or carbon monoxide, nitrogen(I)-oxide (N_2O) or nitrogen-suboxide and nitrogen(II)-oxide (NO) or nitrogen-monoxide.

Sulphur (S, lat. sulfur) is one of the oldest known elements.
At ordinary temperature, sulfur is weakly active.
Sulfur does not cause severe poisoning, but can cause irritation of the mucous membranes of the nasal passages and eyes.
Sulfur makes up 0.16% of body weight.
It is a component of some **amino acids - cysteine and methionine**, which are part of proteins.



methionine



biotin

Sulfur is also an important component of biomolecules such as taurine, coenzyme A, S-adenosylmethionine and important body vitamins such as thiamin (B1) and biotin (H). Sulfur can be found in the body in an inorganic form as sulfate.

Sulfur dioxide (SO_2) is produced by burning sulfur in the air. It is a colorless gas with a suffocating smell. It is heavier than air. It dissolves in water. The resulting solution is acidic because the gas (acidic oxide) reacts with water to form sulfuric acid (H_2SO_3).

Acid rain is caused by emissions of sulfur dioxide and nitrogen oxides, which react with water molecules in the atmosphere and form acids.

Sulfur dioxide is emitted as a by-product from cars and factory chimneys, polluting the environment. Inhalation of large amounts of SO_2 causes acute poisoning.

Sulfur(VI)-oxide (SO_3, sulfur-trioxide) is an acidic oxide that gives sulfuric acid with water.

$$SO_3 + H_2O \rightarrow H_2SO_4 \quad D_rH = -89{,}1 \text{ kJ/mol}$$

Sulfuric acid H_2SO_4 and its salts, sulfates, and hydrogen sulfates are significant compounds. Sulfuric acid is a colorless oily liquid (ρ = 1,84 g/cm^3). It is a strong acid and a good oxidizing and dehydrating agent.

$$H_2SO_4 + H_2O \rightarrow HSO_4^- + H_3O^+$$
$$HSO_4^- + H_2O \rightleftarrows SO_4^{2-} + H_3O^+$$

All mineral acids, including sulfuric, are added to water, not the other way around.

Hydrogen sulphide H_2S is a gas with an unpleasant odor reminiscent of rotten eggs. It is very poisonous, about four times more poisonous than CO, and approximately like hydrogen cyanide. It is found in some mineral waters, in volcanic gases, and many spas are known for their sulfurous waters that smell of this gas.

Selenium

(Se, Latin: sellenium) is an essential trace element and metalloid
selene = Moon (always appeared with the next element of this group tellur, lat. tellus - Earth).

Selenium-rich foods are: Brazil nuts (the richest food source of selenium), sunflower seeds, dates (contain three times more selenium than bananas), bananas, grapes, berries, brown rice, barley and garlic. The properties of selenium are similar to those of sulfur.

Selenium is an essential mineral that greatly contributes to strengthening immunity. It is an extremely important antioxidant micronutrient, has a rejuvenating effect and protects against cancer. Selenium in very small amounts is necessary for cellular function in many living things. Selenium plays an important role in the body in protection against heart attack, angina pectoris, poisoning (necrosis of the liver), rheumatic-arthritic diseases, disturbances in the conduction of nerve impulses and strengthening of the immune state. It is a component of the antioxidant enzyme glutathione-peroxidase, which catalyzes the reactions of "neutralization" of reactive oxygen species, such as peroxides and thioredoxin reductases (indirectly reducing certain oxidized molecules in the animal organism and some plants).

A large deficiency of selenium can lead to infertility in men as well as in women. Selenium is an ingredient in some mineral waters, multivitamin preparations and other dietary products.