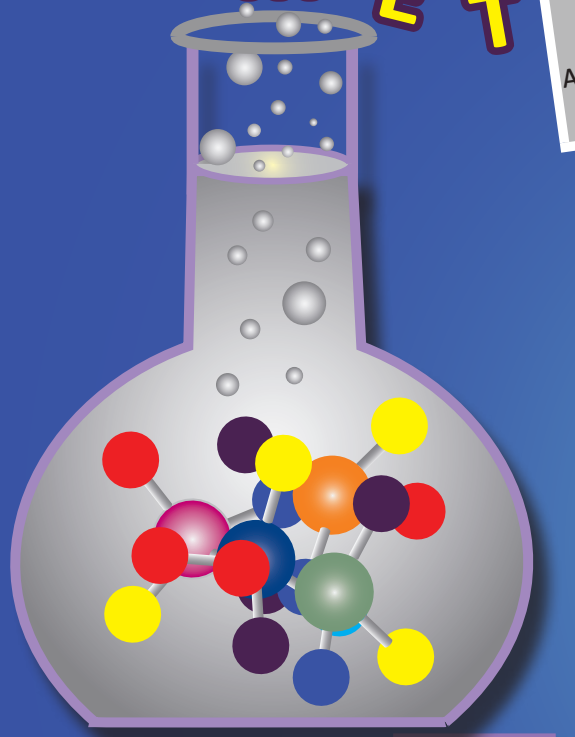
METALS 13 Al ALUMINUM 16 S SULFUR and THEIR COMPOUNDS



Alkali metals Li Na K Rb Cs

Magnesium Mg

Alkaline earth metals Ca Sr Ba

Aluminum Al

Transition metals Fe Zn Cu Ni

Precious metals Ag Au Pt

7 METALS
Magnesium Mg. Calcium Ca. Aluminum Al 3

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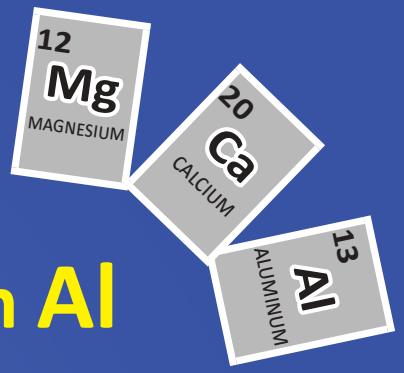
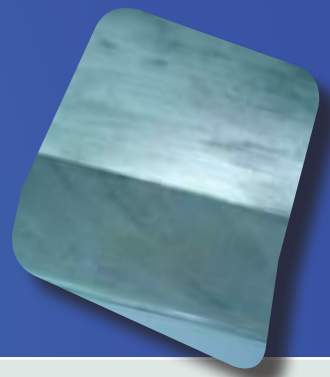
7 METALS

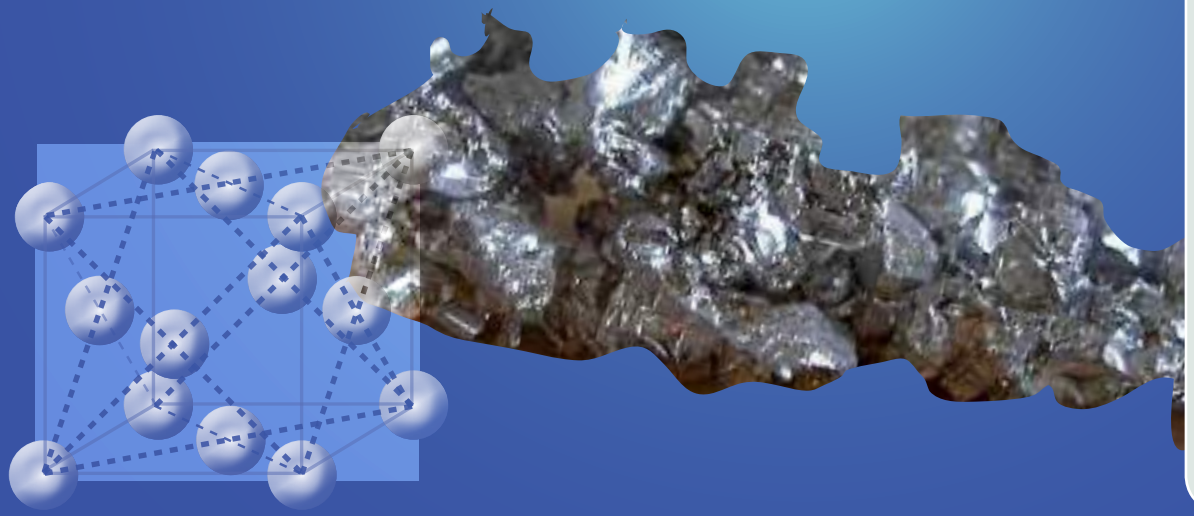
Magnesium Mg. Calcium Ca. Aluminum Al



KEY TOPICS

1. What are metals?
2. Where to find metals in the periodic table?
3. Why are metals good conductors of heat and electricity?
4. How do metals react?





KEY WORDS

- Metallic element
- Metals
- Metallic crystal lattice
- Electron gas
- Active metals
- Burning of metals
- Aluminates

WHAT ARE METALS?

Generally, metals are simple substances of *metallic elements* but we often use the word „metals“ both for the elements and their simple substances. More than 75 % of the chemical elements are metals. Nevertheless their physical and chemical properties are similar.

There are many metals but their properties are similar.

Gold, silver and copper are some of the most plastic metals

All metals are odourless shiny (with metallic lustre) solid substances except mercury Hg (the only liquid metal at STP*). Caesium Cs melts at 28 °C and gallium Ga – at 37 °C.

Usually metals are silvery white substances but some metals are coloured – copper Cu is reddish, gold Au is yellow.

Metals are malleable and ductile. Therefore they can be formed into thin sheets (foils) or drawn into wires. The most malleable metal is gold Au. It is also the most ductile metal. The second most malleable metal is aluminum Al.

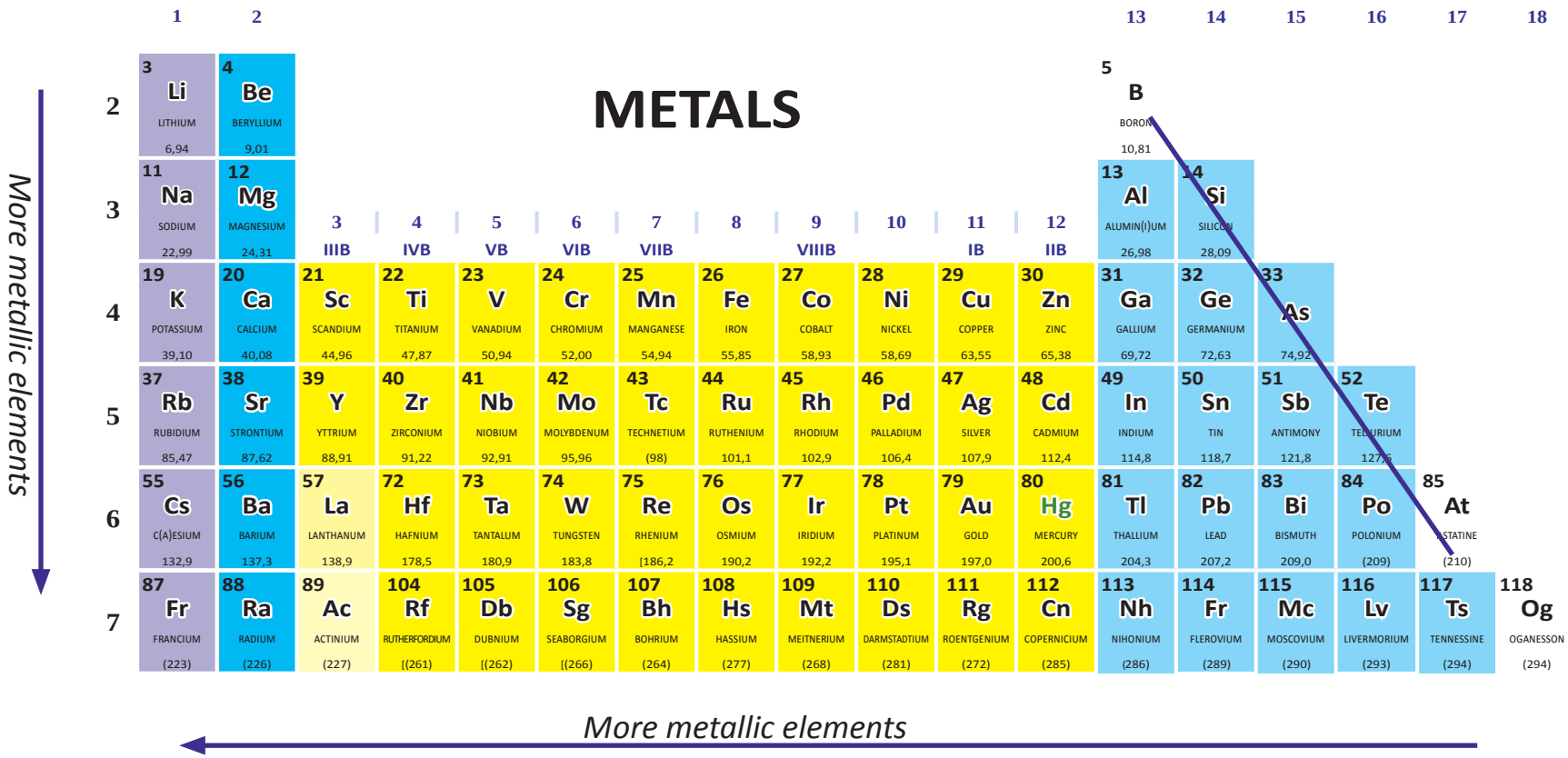
Metals conduct heat and electrical current. The electrical conductivity of silver Ag is the best among all metals.

The lightest metal found in nature is lithium Li (its density is 0,53 g/cm^3), while osmium Os is the heaviest one – its density is 22,6 g/cm^3.

Gallium melts if you hold it in your hand.

*STP – Standard Temperature 273,15 K (O °C) and Pressure 101 325 Pa

In the periodic table metallic elements are located to the left of the virtual line linking Boron **B** and Astatine **At**.



Across a period the metallic properties (we also say „metallic character“) of elements become less pronounced. Down a main group elements become more metallic.

The most metallic element found in nature is caesium **Cs**. It is located in the sixth period and 1 (IA) group. Francium **Fr** (just below caesium) must be more metallic but it is radioactive.

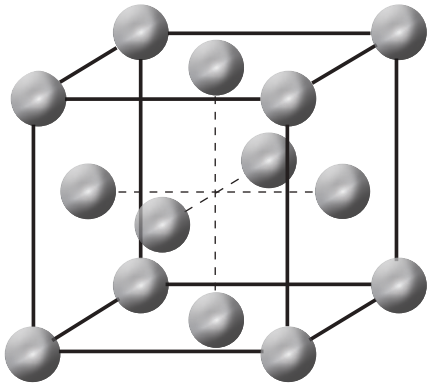
Typical metals are the alkali metals – the elements of 1 (IA) group (besides caesium, also lithium **Li**, sodium **Na**, potassium **K** and rubidium **Rb**) and the elements of 2 (IIA) group (magnesium **Mg** and the alkaline earth metals – calcium **Ca**, strontium **Sr** and barium **Ba**). Metallic are also aluminum **Al**, the elements of the secondary groups – from 3 (IIIB) to 12 (IIB) (for example iron **Fe**, zinc **Zn**, chromium **Cr**, manganese **Mn**, etc.) known as *transition metals*.

SIMPLE SUBSTANCES OF MAGNESIUM Mg , CALCIUM Ca AND ALUMINUM Al

STRUCTURE AND PHYSICAL PROPERTIES

MAGNESIUM Mg and **CALCIUM Ca** are group 2 (IIA) elements. **ALUMINUM Al** is a group 13 (IIIA) element. At STP these metals are solid silvery white substances with metallic luster, good conductors of heat and electricity.

All three metals are crystalline substances. Their atoms are closely packed in metallic crystal lattices – a regular arrangement of metal atoms whose valence electrons are *delocalized* and move freely within the lattice thus forming the „electron sea“. The arrangement of atoms in the lattices of calcium and aluminum is the same – three dimensional face-centred cubic structure. 8 atoms are positioned at the vertices of a cube and additionally 6 atoms are placed in the centre of each surface of the cube. This 14-atoms arrangement is repeated many times in all three directions of the space. The structure of the magnesium lattice is more complex.



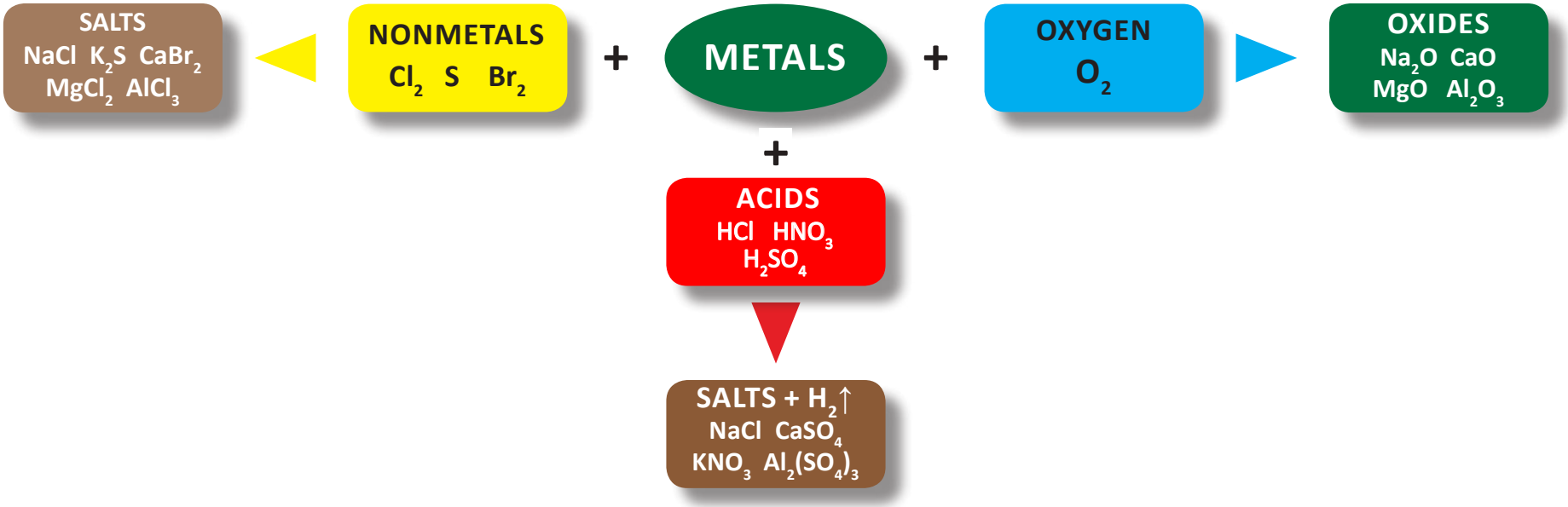
UNIT CELL OF ALUMINUM Al AND CALCIUM Ca

As in all metals the easily moving delocalized electrons assure the electrical and thermal conductivity of magnesium, calcium and aluminum as well as their malleability and ductility – the aluminum foil is a well known product. The electrical conductivity of aluminum is about 60 % of that of copper. Its thermal conductivity is also impressionable.

CHEMICAL PROPERTIES OF METALS

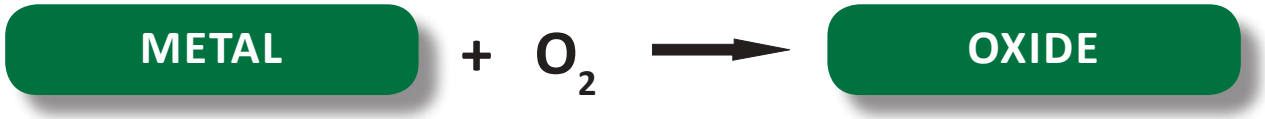
Generally metals are active substances but the most active metals are the alkali metals (group 1 (IA)) – Li, Na, K, Rb and Cs). The metals of 2 (IIA) group – Mg and the alkaline earth metals (Ca, Sr and Ba) are also considered as active metals.

Typical for metals are the reactions with *oxygen*, *nonmetals* and *acids.* In all reactions the reactants are simple substances and the products – chemical compounds: *oxides* Na_2O, CaO, MgO, Al_2O_3 and *salts* NaCl, $CaSO_4$, KNO_3, $Al_2(SO_4)_3$, etc.:



REACTIONS WITH OXYGEN O_2

Active metals react with oxygen and form oxides:



Magnesium and calcium are 2 (IIA) group elements and both have two electrons in their outermost electron shells. So both are divalent in their oxides.

Magnesium burns vigorously with a typical bright white flame. The temperature rises up to more than 2 000 – 3 000 ^{o}C. A white powder of magnesium oxide MgO is formed:

$$2Mg + O_2 \xrightarrow{t^o} 2MgO$$

Magnesium oxide

BURNING MAGNESIUM LOOKS LIKE THAT

Pure magnesium powder or magnesium ribbon are highly flammable. Magnesium is an explosive hazard. Safety glasses with welding eye protection are obligatory when looking at burning magnesium as the light of its bright white flame damages eyes.

The burning magnesium cannot be quenched with water or a carbon dioxide fire extinguisher because it reacts with both compounds (H_2O and CO_2). The fire must be covered with sand to block the access of air or a special dry chemical fire extinguisher must be used.

Calcium burns in air with an intense flame coloured in orange-red* and transforms into white calcium oxide CaO:

$$2Ca + O_2 \xrightarrow{t^o} 2CaO$$

Calcium oxide

Calcium can react with oxygen without heating too. In air it covers with a thin yellowish layer of oxide mixed with other compounds. That is why it is kept under petroleum or in a hermetically closed vessel.

Aluminum reacts with oxygen at normal temperature. As it is a 13 (IIIA) group element it is trivalent and the chemical formula of its oxide is Al_2O_3:

$$4Al + 3O_2 \rightarrow 2Al_2O_3$$

Dialuminum trioxide

The oxide forms a thin surface coating, the access of oxygen is blocked and the reaction stops. But if aluminum powder is placed in a flame it burns with a dazzling light and a very great amount of heat is released (more than the other metals do).

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*You can find many interesting videos about burning metals on YouTube

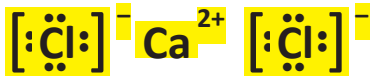
REACTIONS WITH NONMETALS

Metals react with nonmetals and the products are salts:

METAL + **NONMETAL** → **SALT**

For example with chlorine Cl_2 magnesium, calcium and aluminum form *chlorides*:

CALCIUM DICHLORIDE
$CaCl_2$



$$Mg + Cl_2 \rightarrow MgCl_2$$
Magnesium dichloride

$$Ca + Cl_2 \rightarrow CaCl_2$$
Calcium dichloride

$$2Al + 3Cl_2 \rightarrow 2AlCl_3$$
Aluminum trichloride

Chlorides are ionic compounds built up of positive metallic ions (Mg^{2+}, Ca^{2+}, Al^{3+}) and negative chloride ions Cl^-.

$CaCl_2$ is sometimes added to milk to assure the required standard content of calcium. That must be noticed on the products labels.

REACTIONS WITH ACIDS

Active metals react with acids. Hydrogen is liberated and salts are produced:

ACTIVE METAL + **ACID** → **SALT** + $H_2\uparrow$

The symbol „↑“ indicates that the substance is evolved in the air.

For example the salts made in the reactions with hydrochloric acid HCl are *chlorides*:

$$Mg + 2HCl \longrightarrow MgCl_2 + H_2\uparrow$$

Magnesium dichloride

$$Ca + 2HCl \longrightarrow CaCl_2 + H_2\uparrow$$

Calcium dichloride

$$2Al + 6HCl \longrightarrow 2AlCl_3 + 3H_2\uparrow$$

Dialuminum trichloride

Copper, silver, gold, platinum and other *precious metals* are less reactive metals. They do not react with hydrochloric acid HCl.

THE SPECIAL BEHAVIOUR OF ALUMINUM

Alkali and alkaline earth metals have only one or two valence electrons. Aluminum is a 13 (IIIA) group element. So in its outermost electron shell it disposes of three electrons to bond to atoms of other elements. This electron configuration determines some nontypical for the other active metals chemical properties – aluminum reacts with both acids and strong bases*, for example the hydroxides of alkali metals (sodium base NaOH, potassium base KOH). The products are salts made up of the atoms of three elements (an alkali metal, oxygen and aluminum) and hydrogen gas. These salts are named *aluminates*, For example in the reaction of aluminum Al with sodium hydroxide NaOH sodium metaaluminate $NaAlO_2$ is formed and hydrogen H_2 is liberated:

Sodium metaaluminate

Pure sodium metaaluminate is a white crystalline substance. It is used to produce aluminum trihydroxide $Al(OH)_3$.

---

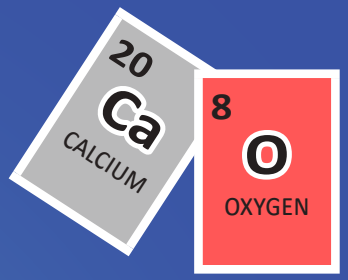
*In Bulgarian language chemical elements capable of reacting with both acids and bases are called *elements with a dual character.*

**This interaction is much complex. Its balanced equation is $\mathbf{2Al + 2NaOH + 2H_2O \rightarrow 2NaAlO_2 + 3H_2\uparrow}$

CAN YOU ANSWER THESE QUESTIONS ?

1. Why are alkali metals the most active metals?
2. Why is caesium Cs the most reactive metal?
3. Are all metals solid substances?
4. Why do metals conduct heat and electricity?
5. What are the typical chemical interactions of metals?
6. Do metals burn?
7. In the early days of photography magnesium powder was used as „lighting powder“. Why?
8. What products are made in the reaction of a metal with a nonmetal?
9. Do all metals react with dilute acids?
10. Do some metals react with both acids and bases?
11. What are aluminates?

8 Basic oxides
Calcium dioxide CaO

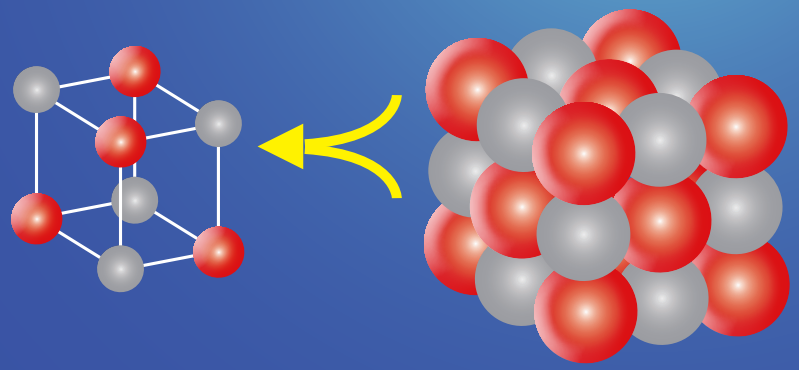


KEY TOPICS

1. What oxides are basic?
2. Why is calcium oxide CaO a basic oxide?
3. What is the difference between quicklime and slaked lime?
4. Why does quicklime convert into calcium carbonate in air?

Ca^{2+}

O^{2-}



KEY WORDS

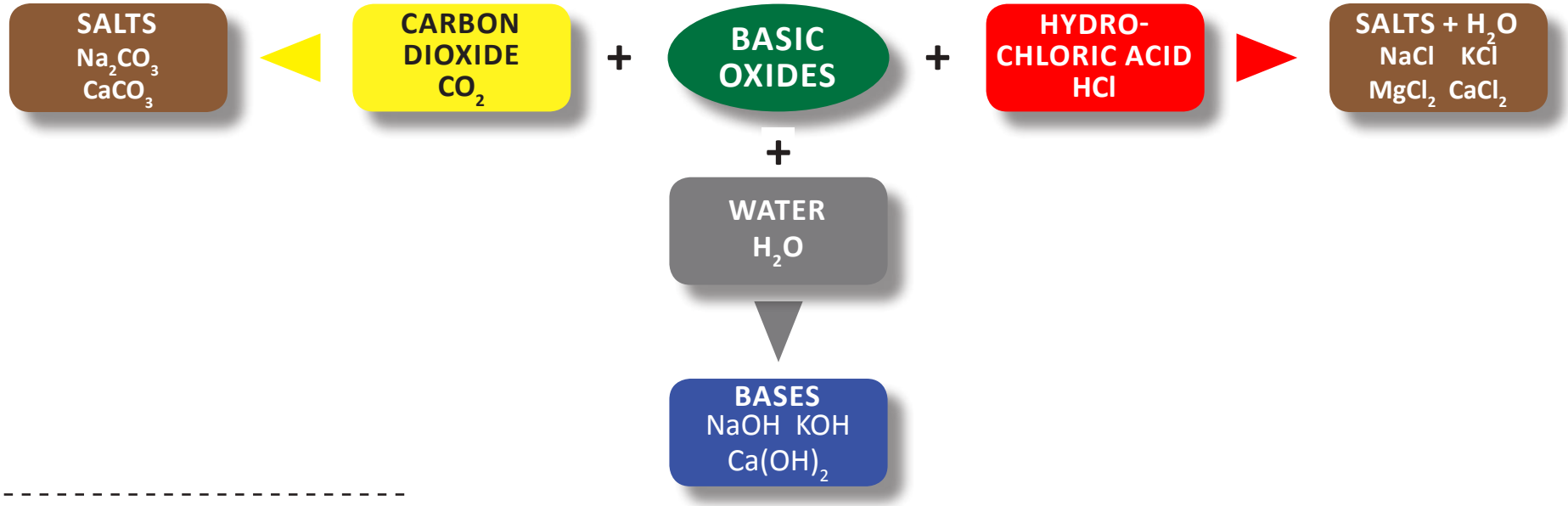
- Basic oxide
- Calcium oxide
- Quicklime
- Slaking of lime
- Slaked lime
- Carbonization
- Limestone

WHAT OXIDES ARE BASIC?

Most of the oxides of metals are insoluble or slightly soluble in water. But the oxides of the alkali metals (Li_2O, Na_2O, K_2O, Rb_2O, Cs_2O) and the oxides of the alkaline earth metals (CaO, SrO, BaO) are soluble in water. These oxides not only dissolve in water but also react with it producing bases – for example NaOH, $Ca(OH)_2$, etc. For this reason the oxides of the typical metals are named *basic oxides*.

All basic oxides are solid crystalline substances as the electronegativity* of the metals and oxygen is quite different. Their ionic lattices are built up of positive metal ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, etc.) and negative oxide ions O^{2-}.

Basic oxides are reactive compounds. Besides the reaction with water, common interactions are the reactions with carbon dioxide CO_2 and hydrochloric acid HCl. In both reactions the products are salts – *carbonates*, for example Na_2CO_3, $CaCO_3$ and *chlorides*, for example NaCl, $MgCl_2$, $BaCl_2$. In the reaction with HCl water is also formed:

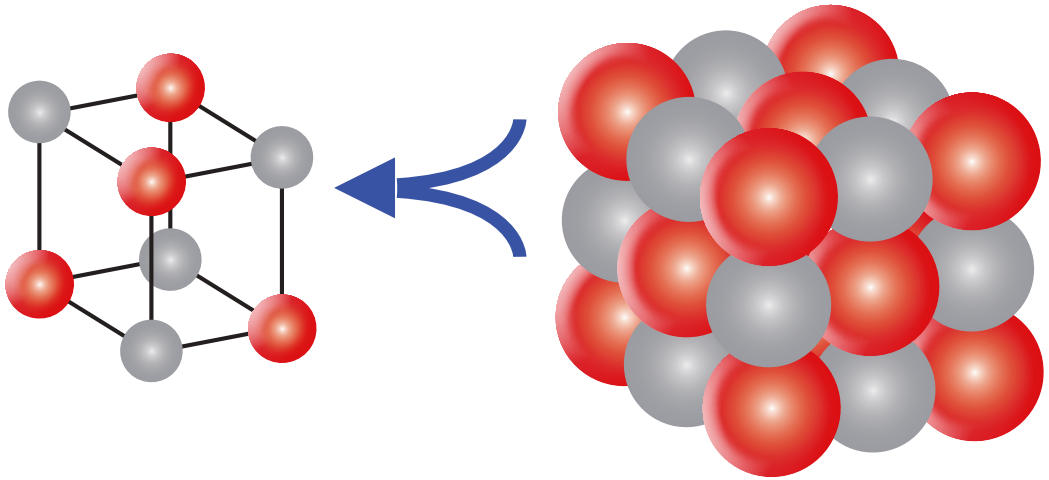


*__Electronegativity__ is a measure of the capability of an atom to attract a bonding pair of electrons.

Calcium oxide CaO

Calcium oxide is a solid white crystalline substance with a simple cubic structure. It is built up of positive calcium ions Ca^{2+} and negative oxide ions O^{2-} located at the vertices of a cube.

As an ionic compound it melts at a very high temperature – more than 2 500 °C. It is about three times heavier than water. In the everyday life It is well known as *quicklime* or simply *lime*.



Crystal lattice of calcium oxide CaO

– calcium ions Ca^{2+}

– oxide ions O^{2-}

CHEMICAL PROPERTIES OF CALCIUM OXIDE CaO

Calcium oxide CaO is a reactive substance. As a basic oxide it reacts with water H_2O, carbon dioxide CO_2 and hydrochloric acid HCl:

REACTION WITH WATER

Calcium oxide absorbs spontaneously water even from air and transforms into a base – $Ca(OH)_2$ calcium dihydroxide (commonly known as *slaked lime*):

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

CaO: Calcium oxide (quicklime)

$Ca(OH)_2$: Calcium dihydroxide (slaked lime)

The process is known as *slaking of lime*. This reaction goes along with the release of a significant amount of heat. The reaction is vigorous and the mixture heats to boiling and can splash and cause burns. It is the bubbling accompanying the reaction that is the reason to name CaO „quick“ lime or „living“ lime.

REACTION WITH CARBON DIOXIDE CO_2

Calcium oxide CaO absorbs spontaneously carbon dioxide CO_2 from air even at room temperature. It transforms into a well known solid insoluble substance – calcium carbonate $CaCO_3$. The process is known as *carbonization* of calcium oxide:

BASIC OXIDE + CO_2 → **SALT**

$$CaO + CO_2 \longrightarrow CaCO_3$$

CaO: Calcium oxide (quicklime)

$CaCO_3$: Calcium carbonate (limestone)

$CaCO_3$ is a mineral – *calcite.* It is the main constituent of *limestone*, *marble* and others. Limestone is a row material for the production of quicklime – under heating it decomposes into CaO and CO_2. This process is known as *burning of lime* and is one of the oldest man made chemical transformations. It is realized in special lime kilns.

REACTION WITH HYDROCHLORIC ACID HCl

As a typical basic oxide calcium oxide reacts with acids, for example with hydrochloric acid HCl. The products are a salt ($CaCl_2$) and water:

BASIC OXIDE + **ACID** → **SALT** + H_2O

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

Calcium oxide — Hydrochloric acid — Calcium dichloride

$CaCl_2$ and $CaCO_3$ are ionic compounds made up of positive calcium ions Ca^{2+} and negative chloride Cl^- and carbonate CO_3^{2-} ions. $CaCO_3$ is insoluble in water while $CaCl_2$ dissolves in water and forms aqueous solutions containing Ca^{2+} and Cl^- ions.

It is interesting to know:

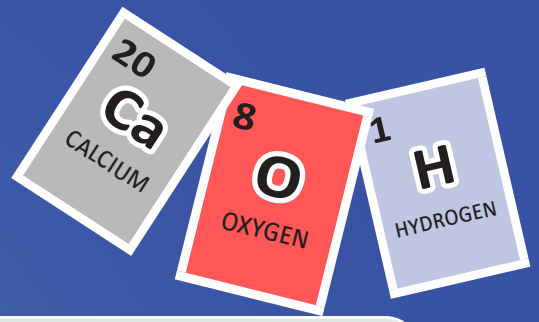
A block of calcium oxide CaO upon heating to incandescence in an oxyhydrogen flame emits a brilliant white light. In the past this phenomenon was used to illuminate theatre stages with the so called limelights. This is in the origin of the expression „to be in the limelight“. Do you know what this means?

CAN YOU ANSWER THESE QUESTIONS ?

1. What oxides are basic? Give examples.
2. What common for all basic oxides chemical interactions do you know?
3. Why is calcium oxide a basic oxide?
4. What is calcium oxide made of?
5. Which of the substances do not react with CaO: NaOH, H_2O and HCl?
6. How is quicklime transformed into slaked lime?
7. Why are safety precautions obligatory when slacking lime?
8. Why should not quicklime be stored in an open container?
9. How to produce calcium oxide? Propose two methods.
10. What is the colour of the litmus paper dipped in a container with slaked lime mixed with water?

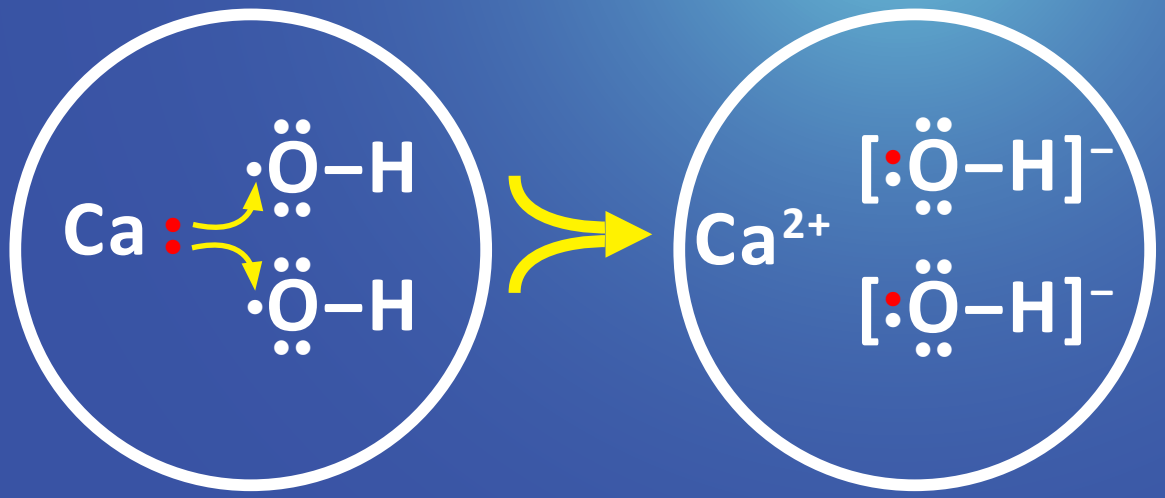
9 Basic hydroxides

Calcium dihydroxide $Ca(OH)_2$



KEY TOPICS

1. What is a basic hydroxide?
2. Why do soluble basic hydroxides liberate OH^- ions in water solutions?
3. Why is $Ca(OH)_2$ a basic hydroxide?
4. Why does the water suspension of $Ca(OH)_2$ harden if exposed to air?

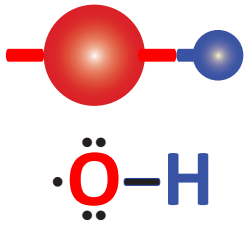


KEY WORDS

- Basic hydroxide (base)
- Hydroxy group –OH
- Hydroxide ion OH^-
- Slaked lime
- Neutralization
- Milk of lime
- Limewater

WHAT IS A BASIC HYDROXIDE?

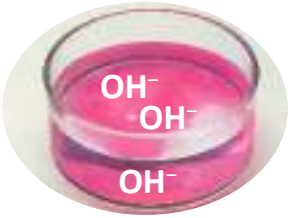
HYDROXIDES are chemical compounds with one ore more *hydroxy groups* –OH. In this diatomic group one oxygen atom **O** is covalently bonded to one hydrogen atom **H**. The „–“ shows that in a compound the oxygen atom of the hydroxy group bonds to another atom of a metallic or a nonmetallic element. If the bonded atom is much less electronegative than the oxygen atom (like all active metals) the hydroxide (if soluble) dissociates in water into positive metallic ions (Na^+, K^+, Ca^{2+}, Ba^{2+}) and negative *hydroxide ions* OH^- as the oxygen – metal bond disrupts. These hydroxides are named basic hydroxides or simply bases.



HYDROXY GROUP
LEWIS DOT FORMULA

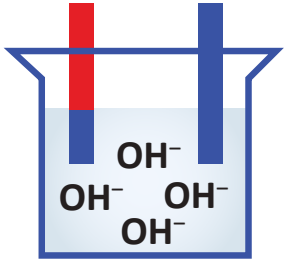
Soluble BASIC HYDROXIDES dissociate in water into positive metal ions Na^+, K^+, Ca^{2+}, Ba^{2+} ,and negative hydroxide ions OH^-.

Usually the term „base“ is used for the compounds of the alkali metals as they have only one hydroxy group – NaOH sodium base, KOH potassium base. The term „hydroxide“ is used to indicate the number of hydroxy groups bonded to one metallic atom – $Ca(OH)_2$ calcium dihydroxide, $Al(OH)_3$ aluminum trihydroxide.



Phenolphthalein is pink-red in aqueous solutions of basic hydroxides

Hydroxide ions OH^- in aqueous solutions are easily detected using litmus or phenolphthalein – litmus turns blue and phenolphthalein is pink-red.



Litmus turns blue in aqueous solutions of basic hydroxides

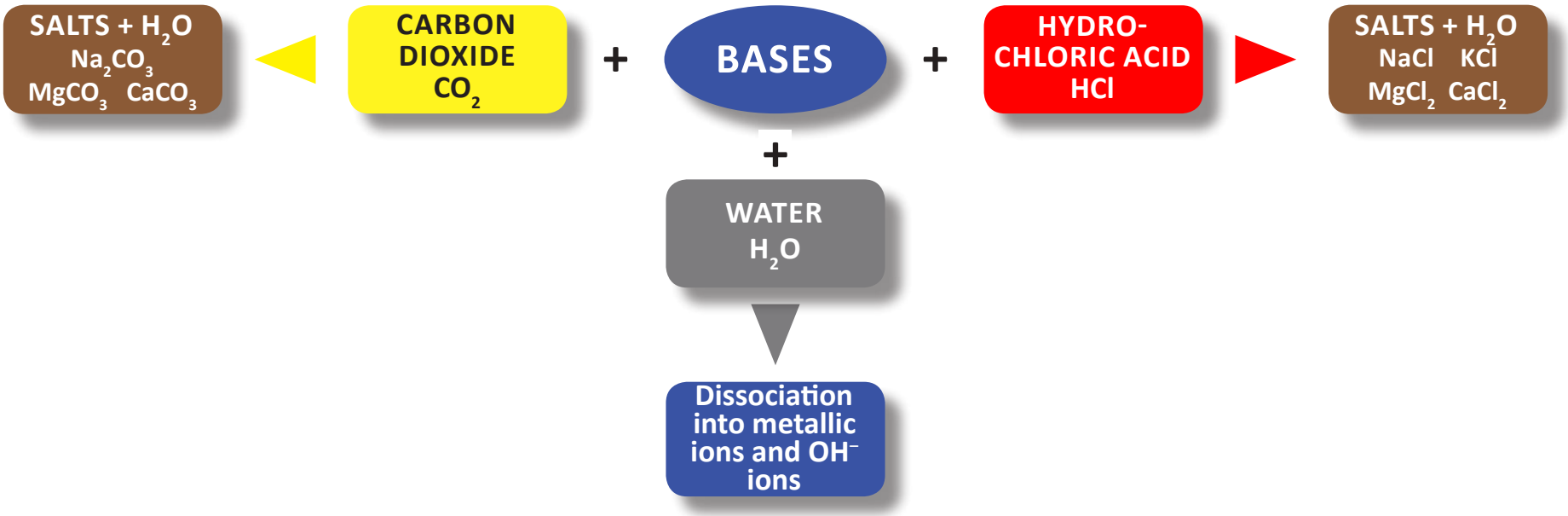
Basic hydroxides are crystalline substances, most of them coloured in white or colourless. Some hydroxides of transition metals are coloured substances – $Cu(OH)_2$ is blue, $Fe(OH)_3$ is brown, $Ni(OH)_2$ is green.

Typical basic hydroxides are the bases of the alkali metals 1 (IA) group: LiOH, NaOH, KOH, RbOH, CsOH. Magnesium and the alkaline earth metals 2 (IIA) group also form basic hydroxides: $Mg(OH)_2$, $Ca(OH)_2$, $Sr(OH)_2$ and $Ba(OH)_2$. All bases of the 1 group elements are well soluble in water while the solubility of the hydroxides of the 2 group elements increases down the group. Most of the hydroxides of the other metals (including transition metals) are practically insoluble substances.

Solid strong bases (like NaOH, KOH) are highly hygroscopic – they readily „retain“ water from air or other surrounding. They are very hazardous in case of skin contact, of eye contact or in case of ingestion. They can cause serious injuries – they burn up the skin and damage the clothes or other tissues. Safety precautions (goggles, protective gloves and an apron) are obligatory when working with such substances.

Safety symbols to indicate the necessary personal protection when working with strong bases

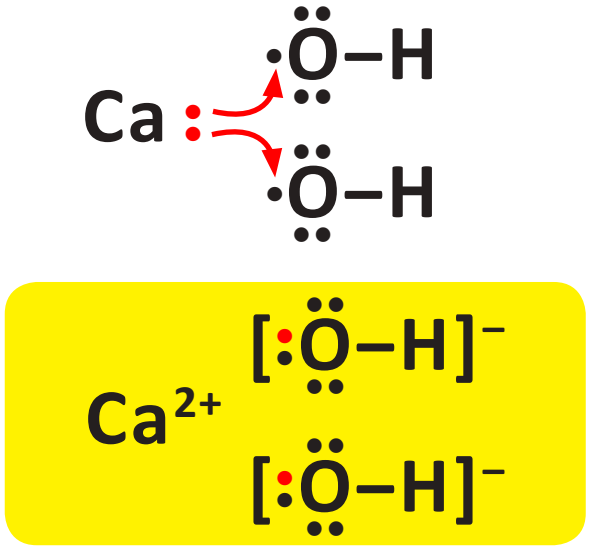
Basic hydroxides (bases) are very reactive compounds. They dissociate in water (if soluble). Similarly to basic oxides they react with carbon dioxide CO_2 and hydrochloric acid HCl. In both reactions the products are water and salts – *carbonates* (for example Na_2CO_3, $MgCO_3$, $CaCO_3$) and *chlorides* (NaCl, $MgCl_2$, $CaCL_2$, $BaCl_2$):



CALCIUM DIHYDROXIDE $Ca(OH)_2$

Calcium dihydroxide $Ca(OH)_2$ (commonly known as *slaked lime*) is a white crystalline powder with a limited solubility in water. One calcium atom Ca is bonded to two hydroxy groups –OH.

Calcium Ca is a 2 (IIA) group element and it has two valence electrons. As calcium Ca is much less electronegative than oxygen O it loses its valence electrons and transforms into a positive ion Ca^{2+}. The oxygen atoms attract the bonding pair of electrons and the hydroxy groups –OH transform into negative ions OH^-. So $Ca(OH)_2$ is an ionic compound.



$Ca(OH)_2$ IS AN IONIC COMPOUND

● – valence electrons of the calcium Ca atom

CHEMICAL PROPERTIES OF CALCIUM DIHYDROXIDE $Ca(OH)_2$

As a typical basic hydroxide $Ca(OH)_2$ dissociates in water and reacts with carbon dioxide CO_2 and hydrochloric acid HCl.

DISSOCIATION IN WATER

Calcium dihydroxide $Ca(OH)_2$ is not very soluble in water but its aqueous solutions colour the litmus in blue and the phenolphthalein solution in pink-red as it dissociates liberating hydroxide ions OH^-:

BASIC HYDROXIDE $\xrightarrow{H_2O}$ **METALLIC IONS** + OH^-

$$Ca(OH)_2 \xrightarrow{H_2O} Ca^{2+} + 2OH^-$$

Calcium dihydroxide — Calcium ion — Hydroxide ions

The chemical properties of the soluble basic hydroxides are similar as OH^- ions are present in the aqueous solutions of these compounds.

REACTION WITH CARBON DIOXIDE CO_2

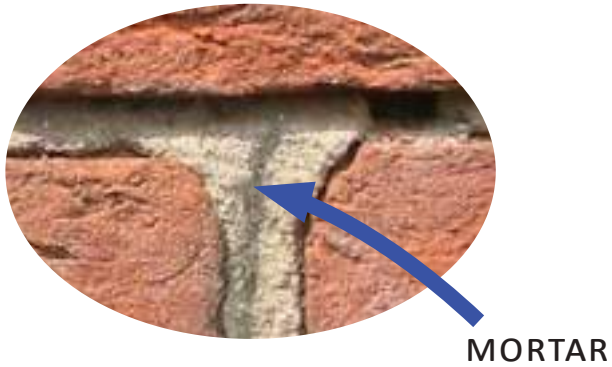
Calcium dihydroxide $Ca(OH)_2$, similarly to sodium base NaOH, reacts with carbon dioxide – the slaked lime absorbs carbon dioxide CO_2 from air and transforms into a salt – calcium carbonate $CaCO_3$:

BASIC HYDOXIDE + CO_2 → **SALT** + **WATER**

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3\downarrow + H_2O$$

Calcium dihydroxide — Calcium carbonate

This process takes place in the new buildings when mortar (a mixture of slaked lime, sand and water) is used as binding material. The humidity is felt for a long period of time as mortar hardens slowly by absorbing CO_2 from the air. Once the *lime mortar* was widely used but it has been supplanted by the *cement mortar* – a mixture of a siliceous material (sand), cement and water. Lime is added to make this plastic mixture smoother.



REACTION WITH HYDROCHLORIC ACID HCl

The reaction of calcium dihydroxide $Ca(OH)_2$ with hydrochloric acid HCl is a reaction of **NEUTRALIZATION** – interaction of a base with an acid. The products are a soluble salt – calcium dichloride $CaCl_2$ and water:

$$Ca(OH)_2 + 2HCl \longrightarrow CaCl_2 + 2H_2O$$

Calcium dihydroxide — Hydrochloric acid — Calcium dichloride

When excess $Ca(OH)_2$ is added to water a suspension, called *milk of lime*, is formed. It is unclear because the slaked lime is not strongly water soluble. The addition of hydrochloric acid HCl makes the mixture clear as the above described reaction of neutralization occurs and the produced salt $CaCl_2$ is highly soluble in water.

A clear aqueous solution of $Ca(OH)_2$ can be prepared by filtering the milk of lime. The clear solution is called *limewater* (do not confuse with lime water – the juice of a lime). In laboratory It is used to absorb carbon dioxide CO_2.

CAN YOU ANSWER THESE QUESTIONS ?

1. What are basic hydroxides?
2. Why do NaOH and $Ca(OH)_2$ manifest similar chemical properties?
3. Does a blue litmus paper turn red if dipped in a suspension of slaked lime? Why?
4. What are the common properties of basic hydroxides?
5. Why is calcium dihydroxide a basic hydroxide?
6. Is slaked lime an amorphous or a crystalline substance?
7. Why is slaked lime an ionic compound?
8. Why does slaked lime harden if exposed to air?
9. What happens when hydrochloric acid is added to a suspension of milk of lime? Why?
10. Upon heating $CaCO_3$ decomposes into CaO and CO_2. How to detect the evolution of CO_2?

10 Amphoteric oxides and hydroxides

Dialuminum trioxide Al_2O_3

Aluminum trihydroxide $Al(OH)_3$

KEY TOPICS

1. What are amphoteric oxides and hydroxides?
2. What are corundum and bauxite?
3. What are the products made in the reactions of amphoteric oxides and hydroxides with acids?
4. What are the products made in the reactions of amphoteric oxides and hydroxides with strong bases?

KEY WORDS

- Amphoteric oxides
- Amphoteric hydroxides
- Corundum
- Bauxite
- Gibbsite (Hydrargilite)
- Metaaluminates

WHAT ARE AMPHOTERIC OXIDES AND HYDROXIDES?

Aluminum manifests some unusual properties – it reacts with both acids (like all active metals) and bases. It can be expected that its oxide Al_2O_3 and its hydroxide $Al)OH)_3$ would also react with both acids and bases. Such oxides and hydroxides are considered as *amphoteric oxides* (In greek language „amphotheros“ means „each of two“). Besides Al_2O_3 and $Al(OH)_3$, the oxides and hydroxides of beryllium Be, zinc Zn, tin Sn, lead Pb also display amphoteric properties.

Amphoteric oxides and hydroxides react with both acids and bases.

DIALUMINUM TRIOXIDE Al_2O_3

CORUNDUM

Al_2O_3 POWDER

Dialuminum trioxide Al_2O_3 is a typical amphoteric oxide. It is a white insoluble in water crystalline substance. It is about four times heavier than water and melts at a very high temperature – more than 2 000 °C. It is found in nature as the mineral *corundum*. Pure corundum is colourless and is a very hard substance. The precious stones sapphire (blue) and ruby (red) are transparent crystals of Al_2O_3 with minor amounts of impurities from oxides of other metals – chromium Cr, iron Fe, titanium Ti.

SAPPHIRE

RUBY

CHEMICAL PROPERTIES OF Al_2O_3

The natural corundum is an inert substance – it does not react either with water or with acids or bases. But upon thermal treatment the structure of dialuminum trioxide Al_2O_3 is modified and it becomes a reactive substance. Reactions with both acids and strong bases can take place.

Al_2O_3 reacts with acids as all basic oxides – the products are a salt and water:

AMPHOTERIC OXIDE + ACID → SALT + H_2O

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

Dialuminum trioxide — Hydrochloric acid — Aluminum trichloride

Unlike the oxides of the typical metals (1 and 2 groups of the periodic table) Al_2O_3 also reacts with strong bases. The products are salts – *aluminates* and water:

$$Al_2O_3 + 2\,NaOH \longrightarrow 2\,NaAlO_2 + H_2O$$

Sodium metaaluminate

Al_2O_3 is mainly used in the industrial production of aluminum. The row material is *bauxite* – a rock containing aluminum in several forms which during the first stages of the industrial process are transformed into Al_2O_3.

ALUMINUM TRIHYDROXIDE $Al(OH)_3$

Aluminum trihydroxide $Al(OH)_3$ is a white spongy gelatinous substance, insoluble in water. It is a typical amphoteric hydroxide.

CHEMICAL PROPERTIES OF $Al(OH)_3$

The amorphous $Al(OH)_3$ reacts easily with strong acids. The products are salts and water:

AMPHOTERIC HYDROXIDE + ACID → SALT + H_2O

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

Aluminum trihydroxide — Hydrochloric acid — Aluminum trichloride

$Al(OH)_3$ also reacts with strong bases. The products are salts (aluminates) and water:

$$Al(OH)_3 + KOH \rightarrow KAlO_2 + 2H_2O$$

Potassium metaaluminate

In both reactions the gelatinous aluminum trihydroxide is gradually dissolved and the soluble salts of aluminum are formed.

$Al(OH)_3$ occurs in nature mainly as the mineral *gibbsite* (also known as *hydrargilite*). It is a crystalline substance and reacts with strong bases only under heating.

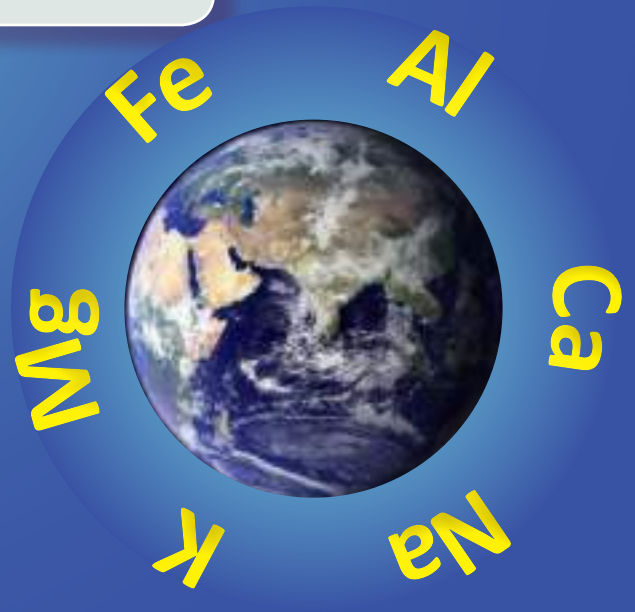
CAN YOU ANSWER THESE QUESTIONS ?

1. Why is aluminum trivalent in both Al_2O_3 and $Al(OH)_3$?
2. Why is Al_2O_3 an amphoteric oxide?
3. Al_2O_3 found in nature is an almost unreactive compound. How does it react with HCl and NaOH?
4. What name is given to the salt produced in the reaction of $Al(OH)_3$ with NaOH?
5. Under heating aluminum trihydroxide decomposes – dialuminum trioxide is obtained and water is liberated. Can you express the chemical equation of this transformation?
6. How to produce $Al(OH)_3$?
7. What is the main ore of aluminum?
8. Is aluminum trihydroxide a crystalline or an amorphous substance?
9. Why is gibbsite less reactive than the amorphous $Al(OH)_3$?

11 Importance of metals and their compounds

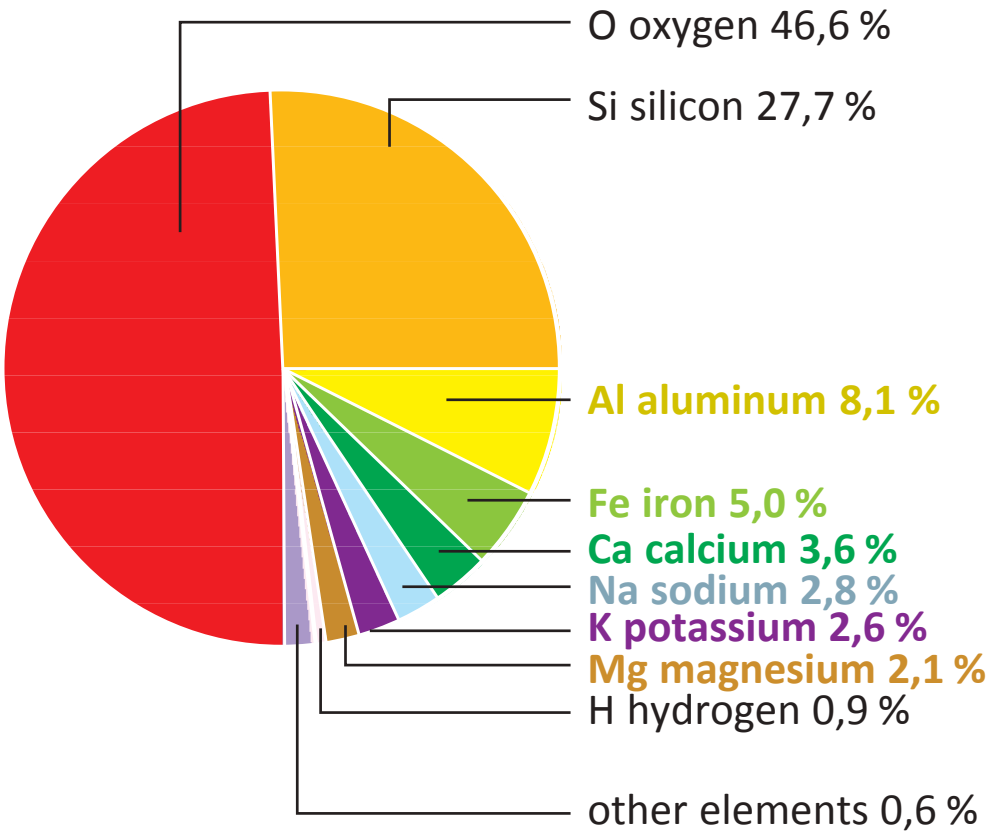
KEY TOPICS

1. Why are metals so important?
2. Why are calcium and magnesium vital for man?
3. What are magnesium, calcium, aluminum and their compounds used for?
4. Why is aluminum recycled?



Most of the chemical elements are metallic but they are not the most abundant elements in nature. In the Earth's crust the most abundant element is oxygen O (almost the half of its mass). Silicon Si comes after it but in spite of its metallic lustre this crystalline substance is not considered as a typical metal. So aluminum Al (only 8,1 % by mass) is considered as the most abundant metal in the Earth crust. Other metallic elements building up the Earth's crust are iron Fe, calcium Ca, sodium Na, potassium K, magnesium Mg.

Active metals are generally found in nature as minerals – more often their oxides or salts. They are row material for the metallurgy – the industrial extraction of metals from their ores, their modification regarding their uses and the production of alloys (materials made of two or more elements, at least one of which is always a metal). Some less active metals are found in nature also as simple substances (gold, silver, copper).



ABUNDANCE OF THE ELEMENTS IN THE EARTH'S CRUST (BY MASS)

METALS are widely used both in the industry and the everyday life. They are important for all living organisms on Earth.

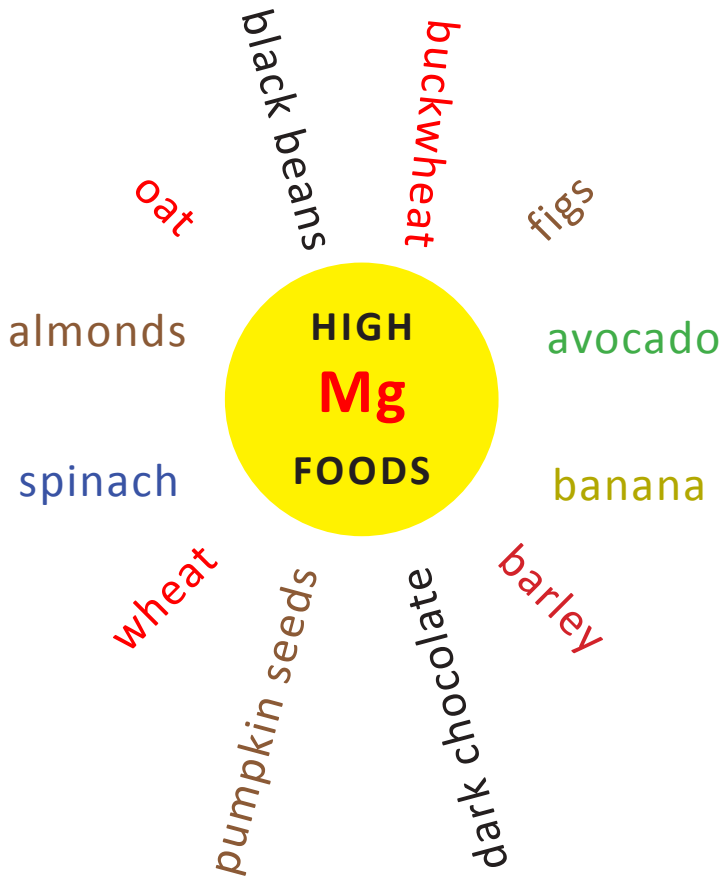
PHYSIOLOGICAL ROLE OF METALS AND THEIR COMPOUNDS

Many metals are important for the normal functioning of living organisms but magnesium and calcium are one of the most important.

MAGNESIUM (Mg^{2+}) is of vital importance for man. It is mainly found in bones but it is also a part of many enzymes that promote thousands of biochemical processes. It is indispensable for the energy production and the synthesis of **ATP** (**A**denosine **T**ri**P**hosphate) – the energy storage „container“ in our bodies. Magnesium plays an important role in the synthesis of **DNA** (**D**eoxyribo**N**ucleic *A*cid) and **RNA** (**R**ibo**N**ucleic **A**cid) on which depend the building of proteins and cells. Magnesium also takes part in the transport of calcium and potassium across cell membranes, thus assuring the nerve impulse conduction, the muscle contraction and the normal heart rhythm. As a whole magnesium is essential for the mineral balance indispensable to maintain life.

Magnesium is also the central element of chlorophyll.

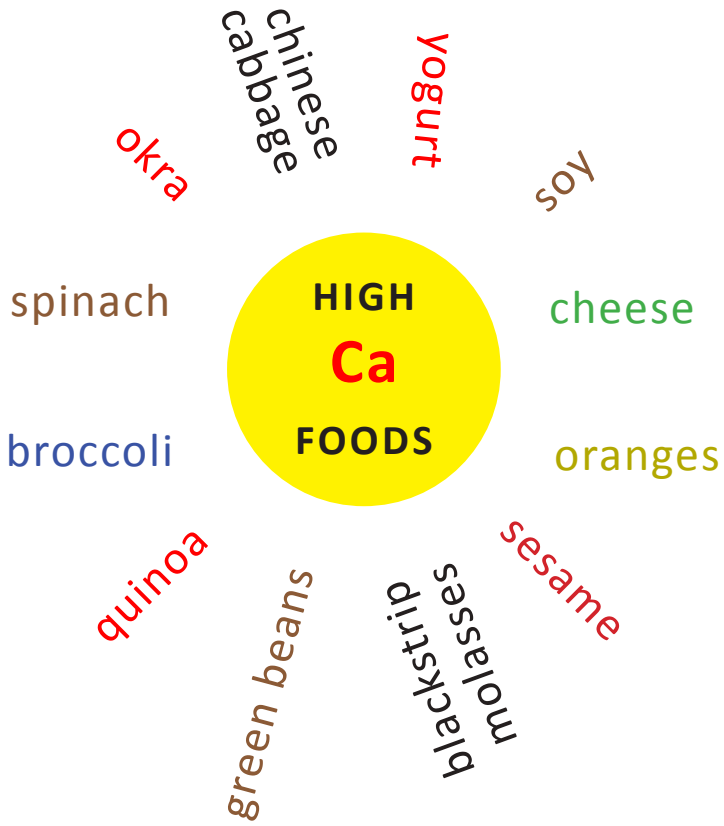
The indispensable amount of magnesium is most provided by the food. So it is important to eat every day magnesium rich foods – vegetables, fruits also some fishes (for example halibut, tuna), some cereals and others.



CALCIUM (Ca^{2+}) is also of vital importance for man. There is more calcium in the body than any other metal – the amount of calcium is about 1,5 % of the body mass. 99 % of it builds up bones and teeth. About only 1 % is in the fluids and the soft tissues. Calcium ions regulate some important biochemical processes – the normal functioning of heart muscles, nervous and blood clotting processes.

One liter blood contains about 0,24 g calcium dichloride $CaCl_2$. If the amount of Ca^{2+} in blood is lower the blood clotting process does not go properly. Calcium is crucial for the normal development of the skeleton in the early age of children.

The daily amount of calcium indispensable for the normal functioning of the human body is supplied by foods. The dairy products (milk, cheese, yogurt), some of the green vegetables (broccoli, spinach, green beans), some cereals (okra, quinoa), also dark chocolate, oranges, molasses and many others are calcium rich foods.



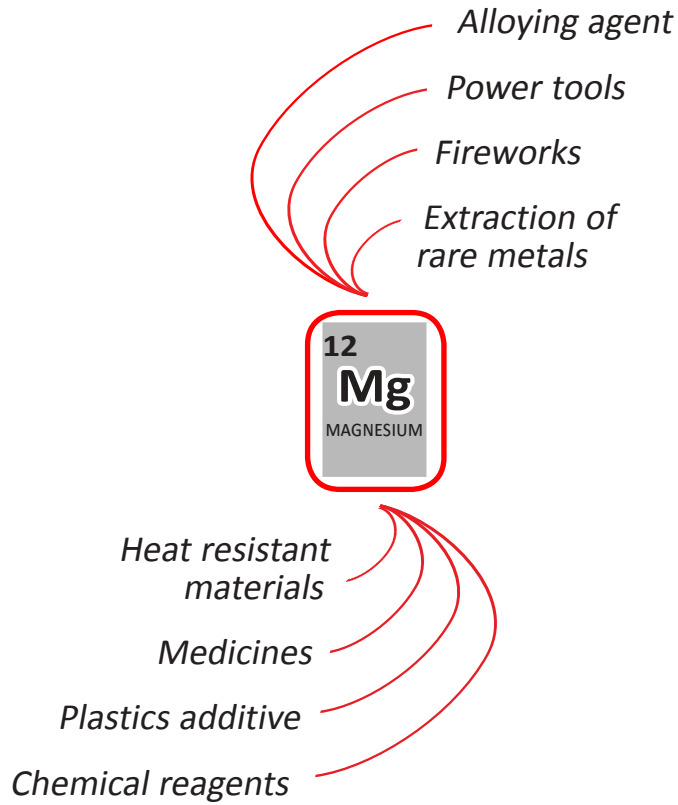
USES OF METALS AND THEIR COMPOUNDS

Metals and their compounds have been used since ancient times. Today scientists even synthesize metallic elements (mainly radioactive metals) that do not occur in nature but for thousands of years humanity has slowly accumulated an enormous amount of knowledge about naturally occurring metals, their extraction from ores and their modification regarding the needs of the industries. Here are the most common uses of magnesium, calcium, aluminum and some of their „most popular“ compounds.

MAGNESIUM Mg is both light and strong. These properties are a key factor for its uses:

- Magnesium is less dense than aluminum and it is added to it to improve the mechanical and welding characteristics of aluminum alloys used in the the aircraft and aerospace technologies;
- As magnesium is light it is used in the production of car seats, luggage, laptop, camera, power tools like electric motors, internal combustion machines and others;
- As magnesium ignites easily in air and burns with a white bright flame it is used in fireworks, flares and sparkles;
- Magnesium can substitute less active metals in their oxides. For this reason it is used in metallurgy to produce rare metals like uranium U;
- Magnesium oxide MgO is used to make heat resistant blocks for fireplaces and furnaces;

- As magnesium ions Mg^{2+} are vital for the normal functioning of living organisms, magnesium salts are added to cattle feed and to soil as fertilizers;
- Magnesium dihydroxide $Mg(OH)_2$ is added to some plastics to retard their aging – the change in their properties with time;
- Gymnasts and weightlifters use powder of magnesium carbonate $MgCO_3$ to improve grip;
- Gringnard reagents are organic magnesium compounds important for the chemical synthesis;
- Magnesium milk $Mg(OH)_2$, magnesium sulfate $MgSO_4$ (Epson salt) and magnesium oil (flakes of magnesium dichloride $MgCl_2$ mixed with water) are medicines.



SOME USES OF MAGNESIUM **Mg**

As a whole magnesium Mg is a quite indispensable metal both for the chemical industry and for the daily man's activities. It is also a key element for the body health.

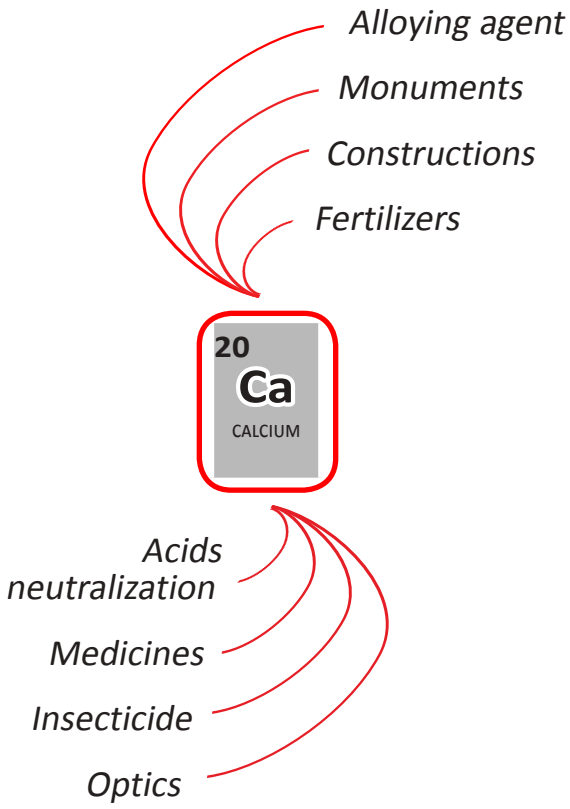
CALCIUM Ca itself and its oxide and hydroxide are reactive substances while its most common salts (gypsum $CaSO_4$ and calcite $CaCO_3$) are not so reactive compounds. That determines their uses:

Calcium compounds (quicklime **CaO**, slaked lime **$Ca(OH)_2$**, limestone **$CaCO_3$**, marble **$CaCO_3$**, gypsum **$CaSO_4$**) are widely used in constructions.

- Calcite $CaCO_3$ (main constituent of limestone and marble) is a mineral found throughout the world. It is used in constructions as a row material to produce cement and concrete. Annually in the world are used tens of millions of tonnes of limestone;
- CaO, $Ca(OH)_2$ and $CaSO_4$ (gypsum) are materials used un constructions;
- Calcium (like magnesium) is used in the production of rare metals – uranium U, thorium Th, zirconium Zr;
- Calcium is an alloying agent added to aluminum, beryllium, copper, lead to modify the alloys properties regarding their final uses;
- Calcium ions Ca^{2+} are vital for many living organisms and calcium salts are often used as fertilizers;
- Slaked lime $Ca(OH)_2$ mixed with $CuSO_4$ is an insecticide commonly known as Bordeau mixture;
- Limestone $CaCO_3$ is a row material to produce quicklime CaO;

- Marble is a material widely used by sculptors. Many of the art masterpieces are made of marble;
- $CaCO_3$ is used to neutralize acids – soils are treated with crushed limestone or marble. They are also dispersed into flowing water contaminated with acids;

Taj Mahal in India, a UNESCO World Heritage Site and a legend of eternal love, is made of white marble



SOME USES OF CALCIUM **Ca**

- $CaCO_3$ is also used to capture the harmful SO_2 evolved during the burning of fossil fuels as it reacts with the gas;
- Calcium difluoride CaF_2 is used in the ceramic industry and also in optics for UV- and infrared protection;
- Calcium dichloride $CaCl_2$ is a drying (dehydrating) agent.

It is obvious that calcium Ca and its compounds are widely used materials.
Calcium is also vital for a healthy body.

IT IS INTERESTING TO KNOW:

The Wonderful bridges
in Rhodope mountains

The eggshells, seashells, the shells of snails, oysters and others are made of calcium carbonate. The beautiful coral reefs and the amazing karst forms are also made of $CaCO_3$.

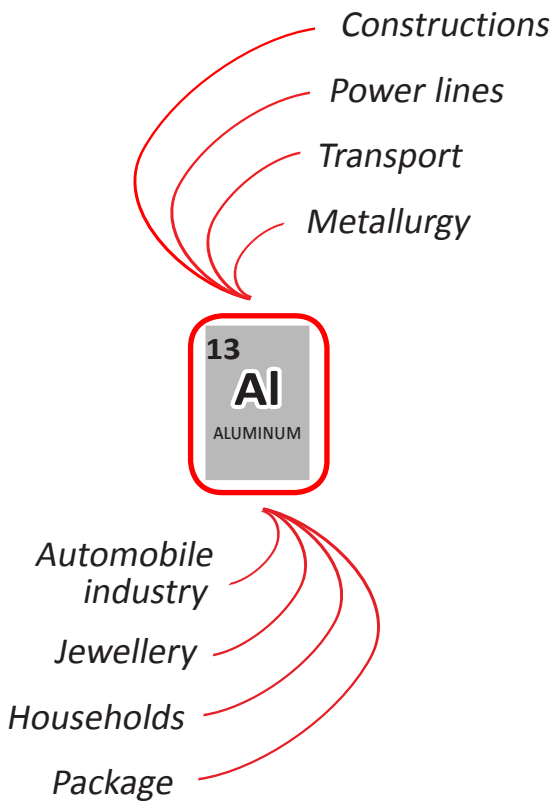
Calcium carbonate is insoluble in water but it reacts with natural underground waters rich in carbon dioxide CO_2. In this slow reaction $CaCO_3$ turns into a relatively more soluble salt – calcium hydrogen carbonate $Ca(HCO_3)_2$:

$$CaCO_3 + CO_2 + H_2O \rightleftarrows Ca(HCO_3)_2$$

This process is reversible. When by some reason the concentration of CO_2 in the underground water drops, the reverse reaction of decomposition of $Ca(HCO_3)_2$ goes on forming deposits of $CaCO_3$. Thus various beautiful natural limestone formations in caves (stalagmites, stalactites) have been created.

ALUMINUM Al Aluminum is the second (after iron) most widely used metal. Millions of tonnes of aluminum are produced each year in the world. Its corrosion-resistance, low density, good electrical and thermal conductivities and low cost are key properties for its uses. Often alloys of aluminum (containing several % of Cu, Zn, Mg, Si, for instance duraluminum) are used as the pure metal is soft and thus its strength is improved:

- Aluminum and its alloys are used in many products requiring the use of light, strong and resistant materials – from cans, foils, kitchen utensils, food packing to part of rockets and airplanes (a boeing 747 contains 66 150 kg of high strength aluminum);
- About one fifth of the total consumption of aluminum is used in constructions – bridges, roofs, stairways, windows frames, doors, railings, indoor and outdoor furniture, etc;
- Although aluminum does not conduct electricity as well as copper and silver, it is used in overhead power lines because it is lighter and cheaper;
- Aluminum is used in cars as it is cheap and light – wheels, engine blocks, handles, mirrors, etc.;



SOME USES OF ALUMINUM **Al**

- Aluminum powder reacts with oxygen upon ignition liberating a great amount of heat. This process is used to produce pure high melting metals (Cr, Mn, V, etc.) from their oxides. This process is known as *aluminothermy*. For example when a mixture of aluminum powder and dichromium trioxide Cr_2O_3 burns dialuminum trioxide Al_2O_3 and chromium Cr are produced;
- Artificial sapphires and rubies are produced by melting at high temperature dialuminum trioxide Al_2O_3 with small amounts of oxides of other metals. The rubies are used not only in jewellery but also in lasers, watches, clocks and weaving looms;
- Aluminum powder can be deposited on the surface of mirrors – a thin layer of protective coating of Al_2O_3 is formed.

Aluminum forms various salts with wide applications:

- Dialuminum trisulfate $Al_2(SO_4)_3$ is used to purify water. $Al_2(SO_4)_3$ dissolves in water forming a gelatinous precipitate of aluminum trihydroxide $Al(OH)_3$. It absorbs the impurities of the solution and precipitates on the bottom of the vessel;
- $Al_2(SO_4)_3$ is also used in the textile industry to improve the fixing of the dyes on the clothes and in the manufacturing of heat resistant materials;
- Alums (double salts like $K_2SO_4.Al_2(SO_4)_3.24H_2O$ or $(NH_4)_2SO_4.Al_2(SO_4)_3.24H_2O$) are used in the leather industry in the process of tanning, in the textile and the paper manufacturing and the photo industry. The paper is treated with alum to prevent the spilling of ink. The alums are also used in medicine to stop bleeding;

- Aluminum trichloride $AlCl_3$ is used in the petroleum refining process, in the production of rubber and plastics as a hardening agent;
- Sodium metaaluminate $NaAlO_2$ is used in the textile and the paper industry, also for the purification of water. In the form of a powder it is added to the concrete (accelerates the hardening of the mixture).

It is evident that aluminum is a metal of great importance both for the modern technologies and the daily life.

Aluminum is also a metal that is worth to be recycled – only 5 % of the energy needed to produce aluminum from ores is required for its recycling.

CAN YOU ANSWER THESE QUESTIONS ?

1. Are metals predominant in the periodic table?
2. Why is it important to eat every day foods rich in magnesium and calcium?
3. What are the key properties of calcium, magnesium and aluminum in terms of their uses?
4. Why is magnesium an alloying agent added to aluminum?
5. Why are magnesium salts used as fertilizers?
6. Which calcium compounds are widely used in constructions?
7. What is common between calcium and art?
8. Where is $CaCO_3$ around you?
9. Why is vinegar (acetic acid) added to to the Easter eggs dyes?
10. Why is aluminum the second (after iron) most widely used metal?
11. Why is aluminum recycled?
12. Where do you find metals in your home?

PROJECTS

1. THE MOST ABUNDANT METAL IN THE EARTH'S CRUST

Is aluminum found in nature as a simple substance? Find out how it is extracted from ores. What is the annual production of aluminum on a world scale (helpful information can be found on the website of the International Aluminum Institute: www.world-aluminum.org). Explain why today aluminum is a widely used metal.

2. MAGNESIUM, CALCIUM AND BODY HEALTH

Explain the role of magnesium and calcium for the functioning and the development of the human organism. Propose a well balanced weekly menu assuring the indispensable daily intake of both elements.

3. THE PRECIOUS METAL OXIDES

What metal oxides are gemstones? How are they transformed into jewellery?

4. METALS IN THE NEW MATERIALS

Learn about some new materials with marvelous properties. What metallic elements do they contain? What is their role?

You can find helpful information on www.cas.org – look at CAS REGISTRY℠ (the gold standard for chemical substance information).