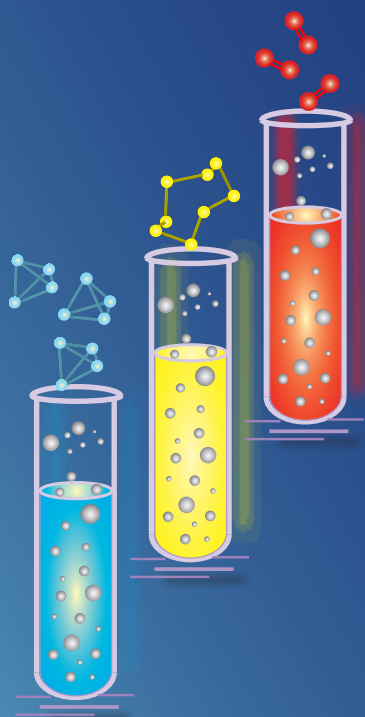


SUMMARY and REVISION



CHEMISTRY is everywhere

- Chemical bonding
- Metals and nonmetals
- Acids and bases
- Organic compounds

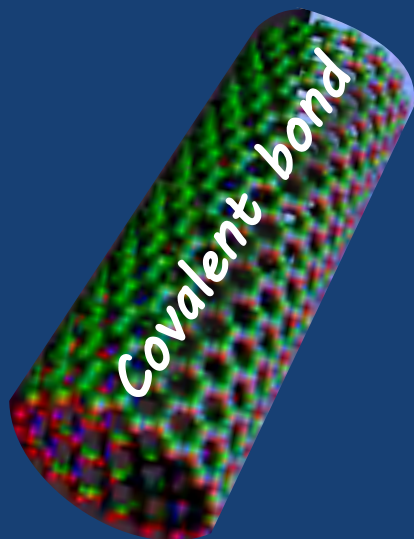
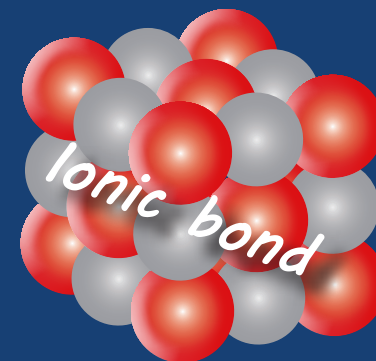
- **C**HEMICAL BONDING **3**
- **M**ETALS, NONMETALS AND THEIR COMPOUNDS **17**
- **O**RGANIC COMPOUNDS **25**
- ▶ **P**ROJECTS **41**

Click on a topic to jump to the page

● CHEMICAL BONDING

KEY TOPICS

1. What is chemical bond?
2. Why are some covalent molecules polar but others are nonpolar?
3. What is the difference between covalent bonding and ionic bonding?
4. Why are metals malleable and ductile?



KEY WORDS

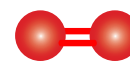
- Chemical bonding
- Covalent bond
- Polar and nonpolar covalent bond
- Polar and nonpolar molecules
- Ionic bond
- Metallic bond

CHEMICAL BONDING – THE FAMOUS PROPERTY OF ATOMS TO LINK TO ONE ANOTHER

118 chemical elements (found in nature and synthesised by man) are known today and scientists continue to make efforts to synthesise new chemical elements with more than 118 protons in their nuclei. But the number of chemical compounds (inorganic and organic, naturally occurring and man-made) is huge (more than 10 millions) and continue to rise rapidly*. This enormous variety is due to the ability of atoms of an element to link to identical or

different atoms, i.e. to form **chemical bonds**.

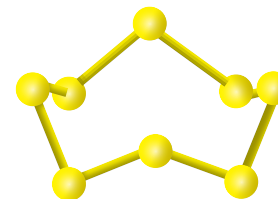
Atoms bond to identical atoms and form molecules of pure elements**. Some of them are diatomic (hydrogen H_2 , oxygen O_2 , halogens – fluorine F_2 , chlorine Cl_2 , bromine Br_2 , iodine I_2). Ozone molecules are made up of three oxygen atoms (O_3). White phosphorous molecules are 4-atomic (P_4). Crystalline sulfur is built up of 8-atomic molecules (S_8). The molecules of plastic sulfur are long zigzag chains. Some atoms link to one another forming one huge molecule. For example, carbon atoms form diamond, graphite, fullerenes, graphene. Metals are also made up of identical atoms.



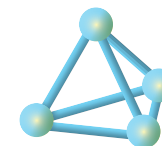
OXYGEN
MOLECULE O_2



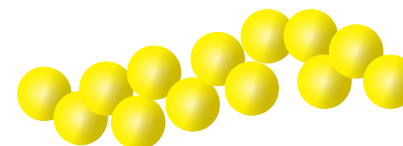
OZONE
MOLECULE O_3



8-ATOMIC MOLECULE
OF SULFUR S_8



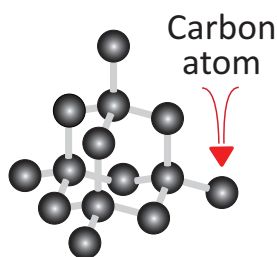
4-ATOMIC MOLECULE
OF WHITE
PHOSPHORUS P_4



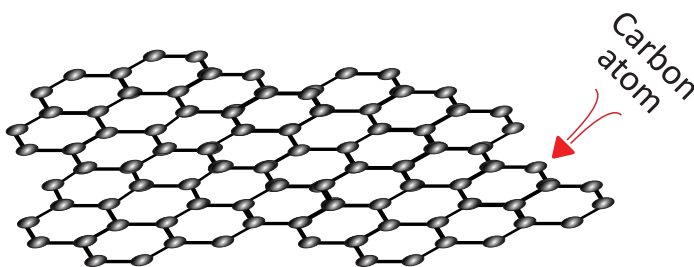
STRUCTURE OF PLASTIC SULFUR



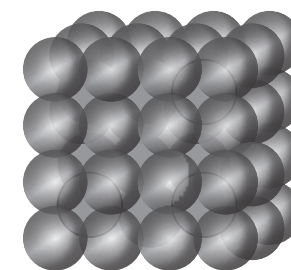
DIAMOND



ATOMIC LATTICE
OF DIAMOND



GRAPHENE

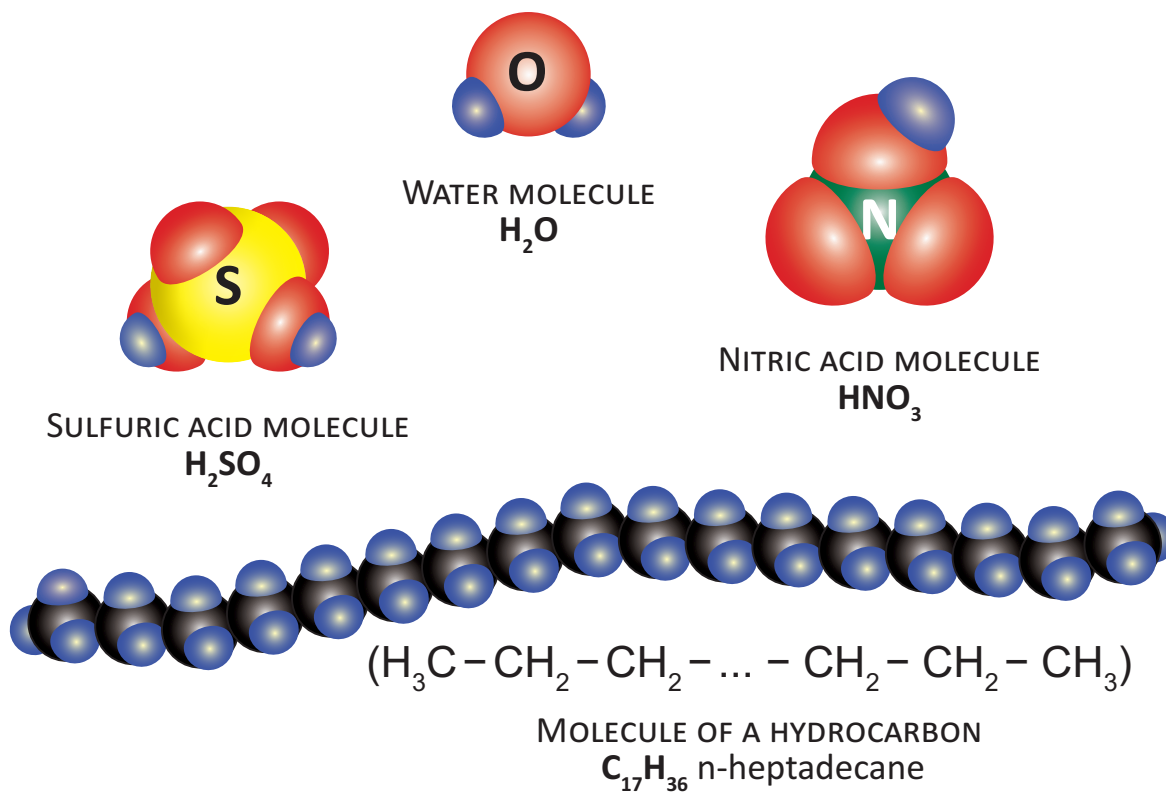


METALLIC LATTICE
OF SODIUM Na

* Information about all known substances is provided by CAS (www.cas.org).

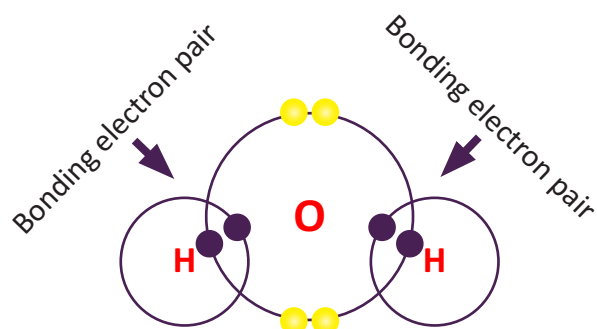
** In Bulgarian language substances made up of identical atoms are called **simple substances**.

Molecules of chemical compounds are made up of atoms of at least two different chemical elements. For example, the molecules of hydrogen halides have only two atoms – one hydrogen atom and one halogen atom (HF, HCl, HBr, HI). The molecules of the most abundant chemical compound on Earth – water H_2O , are made up of three atoms – one oxygen atom and two hydrogen atoms. The molecules of nitric acid HNO_3 have 5 atoms of three elements – one hydrogen atom, one nitrogen atom and three oxygen atoms. The molecules of sulfuric acid H_2SO_4 are built up of 7 atoms – two hydrogen atoms, one sulfur atom and four oxygen atoms. Molecules of organic compounds may contain atoms of only two elements (all hydrocarbons are made up of carbon and hydrogen atoms) but the number of atoms may be huge (even millions).

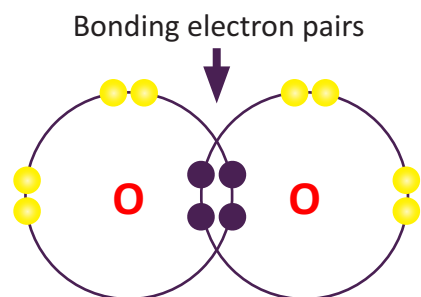


COVALENT BONDING

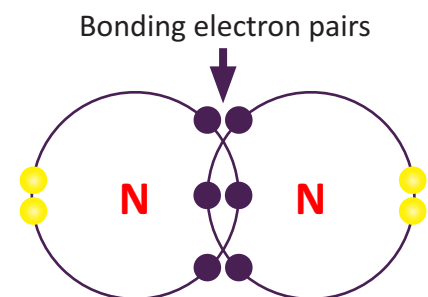
All atoms are built up of a nucleus and moving around it electrons located on electron shells. Atoms always use electrons from the outer electron shells (their valence electrons) to form electron pairs with the valence electrons of other atoms thus forming chemical bonds. If the electronegativity* of the bonding atoms is similar, one, two or three electron pairs may be shared between their nuclei. This type of bonding is called **covalent bonding**. For example:



Bonding of one oxygen atom to two hydrogen atoms in a water molecule H_2O

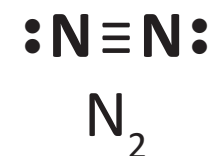
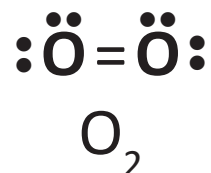
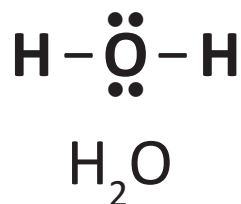


Bonding of two oxygen atoms in a O_2 molecule



Bonding of two nitrogen atoms in a N_2 molecule

Lewis dot formula are often used to represent the bonds formation – the bonding atoms are linked by short straight lines „–“ connecting their chemical symbols. One line corresponds to one shared electron pair. The unused valence electron pairs (called „lone pairs“) are depicted as double dots near the chemical symbol of the element „••“.

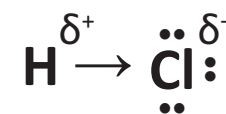


*The capability of atoms to attract the bonding pairs is called **electronegativity χ** .

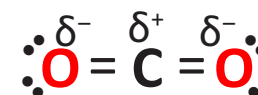
The number of electron pairs shared between bonding atoms determines the **multiplicity** of the chemical bond – **single bonds** (only one shared electron pair), **double bonds** (two shared electron pairs) and **triple bonds** (three shared electron pairs). Double and triple covalent bonds are considered as **multiple bonds**, while single bonds are also called **simple bonds**. Thus, in the water molecules H_2O an oxygen atom is single bonded to two hydrogen atoms. Oxygen atoms are double bonded in an oxygen molecule O_2 . Nitrogen atoms are triple bonded in a nitrogen molecule N_2 .

Depending on the difference in the electronegativity of the bonding atoms covalent bonds are **polar** or **nonpolar**. When the bonding electron pairs are shared between identical atoms (as in O_2 , N_2 , Cl_2) none of them acquires a partial electrical charge – the bond is nonpolar. When different atoms bond, the shared electron pairs are attracted by the nuclei of the more electronegative atom. It acquires a partial negative charge δ^- , while the less electronegative atoms acquires a partial positive charge δ^+ . The bond is polar. For example, in HCl molecules the bonding pair is attracted by the chlorine atom, in CO_2 molecules – by the oxygen atoms.

Depending on the molecules symmetry covalent molecules are **polar** or **nonpolar**. If the outstanding atoms are evenly distributed around a central atom, molecules as a whole are nonpolar in spite of the polarity of the atom-atom bonds. Molecules of CO_2 are linear and symmetrical and the partial negative charges of the more electronegative oxygen atoms are cancelled by the partial positive charge of the central carbon atom. CO_2 molecules are nonpolar.

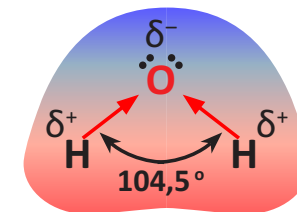


POLAR BOND
IN THE HYDROGEN CHLORIDE
MOLECULE HCl



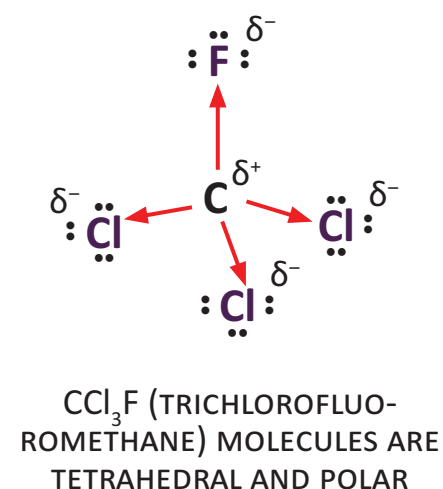
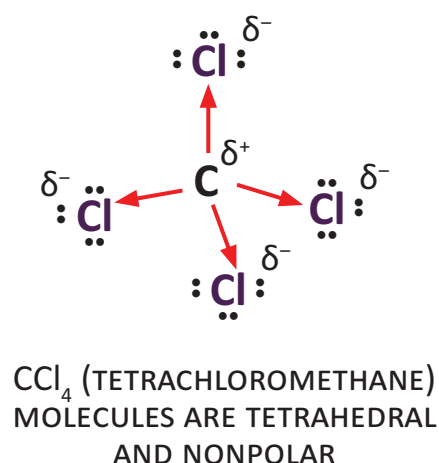
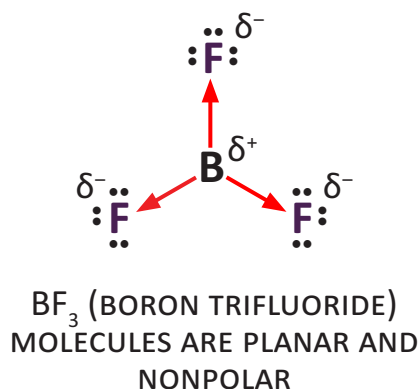
POLAR BONDS
IN THE CARBON DIOXIDE
MOLECULE CO_2

Water molecules H_2O are not linear. They are bent and the partial positive charges of the two hydrogen atoms can not be cancelled by the partial negative charge of the more electronegative central oxygen atom. A dipole* is formed and water molecules are polar – one side of the molecule is more positive (coloured in red) while the other side of the molecule is more negative (coloured in blue).



THE WATER MOLECULE H_2O IS POLAR.

The planar trigonal molecules of BF_3 (boron trifluoride) and the tetrahedral molecules of CCl_4 (tetrachloromethane) are nonpolar. The outside fluorine F and chlorine Cl atoms are evenly distributed around the central atom. But the molecules of CCl_3F (trichlorofluoromethane or freon-11) are polar – the three chlorine atoms and the fluorine atom are unevenly distributed around the central carbon atom. The carbon-fluorine bond is more polar than the carbon-chlorine bonds as the electronegativity of fluorine atoms is greater than the electronegativity of chlorine atoms. As a result the partial positive charge of the central carbon atom can not cancel the partial negative charges of the outside chlorine and fluorine atoms.

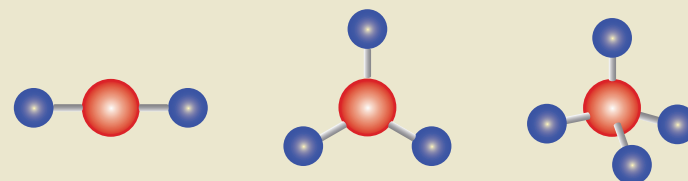


Remember that in spite of their polarity molecules are always electrically neutral units (in the water molecule there are 10 protons and 10 electrons).

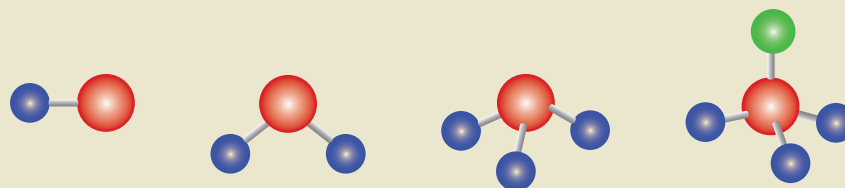
***Electric dipole** is a pair of equal and opposite electric charges separated over a short distance.

KEY POINTS:

- ▶ **COVALENT BONDING** is a chemical link of two atoms by means of one, two or three electron pairs shared by bonding atoms.
- ▶ Identical atoms of nonmetals link to each other by covalent nonpolar bonds.
- ▶ Bonds are polar if there is a difference in the electronegativity of the two bonding atoms. The greater is the electronegativity difference between bonding atoms, the more polar the bond is.
- ▶ Covalently bonded atoms form polar or nonpolar molecules.
- ▶ Molecules built up of identical atoms and molecules built up of a central atom and symmetrically distributed around it identical atoms are nonpolar. The partial negative charges cancel the partial positive charges.
- ▶ Polar molecules are not symmetrical.



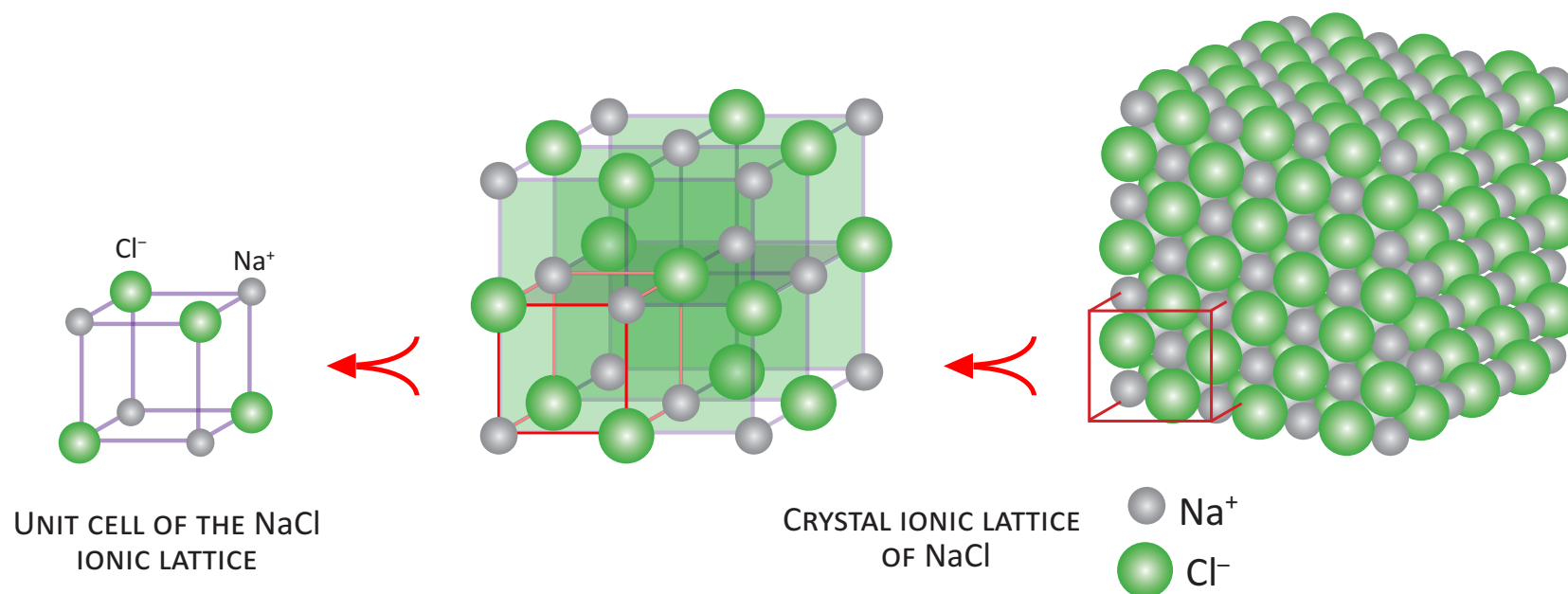
NONPOLAR SYMMETRICAL MOLECULES



POLAR NONSYMMETRICAL MOLECULES

IONIC BONDING

When a metal atom bonds to a nonmetal atom, the bonding electron pair is strongly attracted by the much more electronegative nonmetal atom. If the difference in the electronegativity of the bonding atoms is greater than **1,7**, it is considered that the valence electrons of the less electronegative atom are transferred to the more electronegative atom. Two oppositely charged ions are formed. They are held together by a strong electrostatic force – an **ionic bond** is formed. For example, the well known table salt NaCl is a ionic compound built up of positively charged sodium ions Na^+ and negatively charged chlorine ions Cl^- – sodium atom loses 1 electron and chlorine atom gains 1 electron. The oppositely charged ions form a 3-dimensional (3D) pattern – an ionic lattice. The chemical formula of an ionic compound is the simplest ratio of the numbers of the oppositely charged neighbour ions in this 3D pattern. For example, NaCl for the ionic compound sodium chloride (table salt).



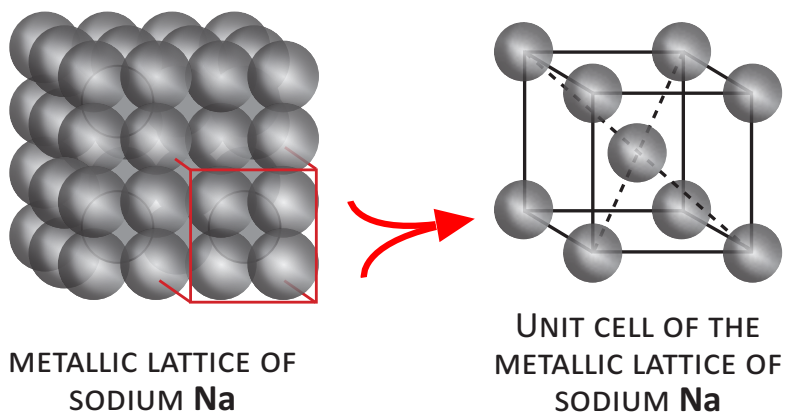
Salts (KI , CaCl_2 , NaBr , CsF , etc.), oxides of metals (Na_2O , MgO , CaO , etc.), hydroxides (NaOH , KOH , Ca(OH)_2 , etc.) are ionic compounds.

KEY POINTS:

- ▶ **IONIC BOND** is a chemical link caused by the electrostatic attraction between oppositely charged ions forming an ionic compound.
- ▶ Ionic bond is formed between atoms with a great difference in electronegativity – usually between metals and nonmetals. The metal atom loses electrons and transforms into a positively charged ion. The nonmetal atom gains electrons and transforms into a negatively charged ion.
- ▶ An ionic bond is considered to be an extremely highly polar covalent bond. It is assumed that the bond is ionic if the difference in the electronegativity of the two bonded atoms exceeds 1,7 ($\Delta X > 1,7$).
- ▶ Ionic compounds are solid crystalline substances. Oppositely charged ions form ionic crystal lattices.
- ▶ Ionic compounds are solids with relatively high melting and boiling points. If soluble in water, they dissociate into ions. Ionic compounds in solution or in molten state conduct electricity.

METALLIC BONDING

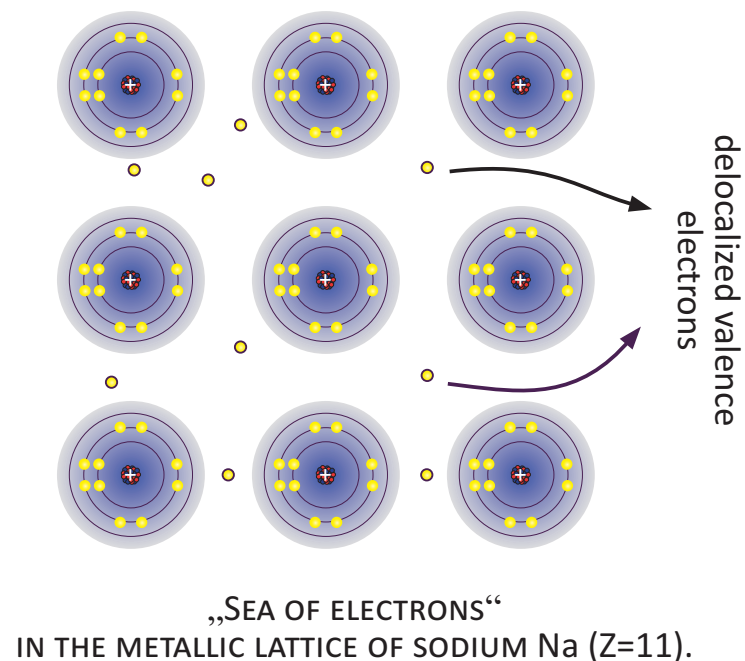
Metals are built up of identical atoms held together by **metallic bonds**. This type of chemical bonding determines their specific physical properties – they are malleable, ductile, conductors of heat and electricity.



Metal atoms form metallic lattices – identical metal atoms form 3D patterns. The valence electrons of all atoms in a metallic lattice are mobile and move freely in the space between the atoms, i.e. they are **delocalized**. Strong electrostatic forces acting between the positive nuclei of the atoms and these „free“ electrons hold the metal crystal together. In metal

lattices there are not many metal – metal bonds. All atoms building the lattice share their valence electrons thus forming the so called „sea of electrons“ (in bulgarian language it is called „electron gas“).

Metals can be deformed without breaking down because under pressure or when stretched metal atoms shift relative to each other but remain linked to one another as the „bonding“ valence electrons move freely inside the lattice.



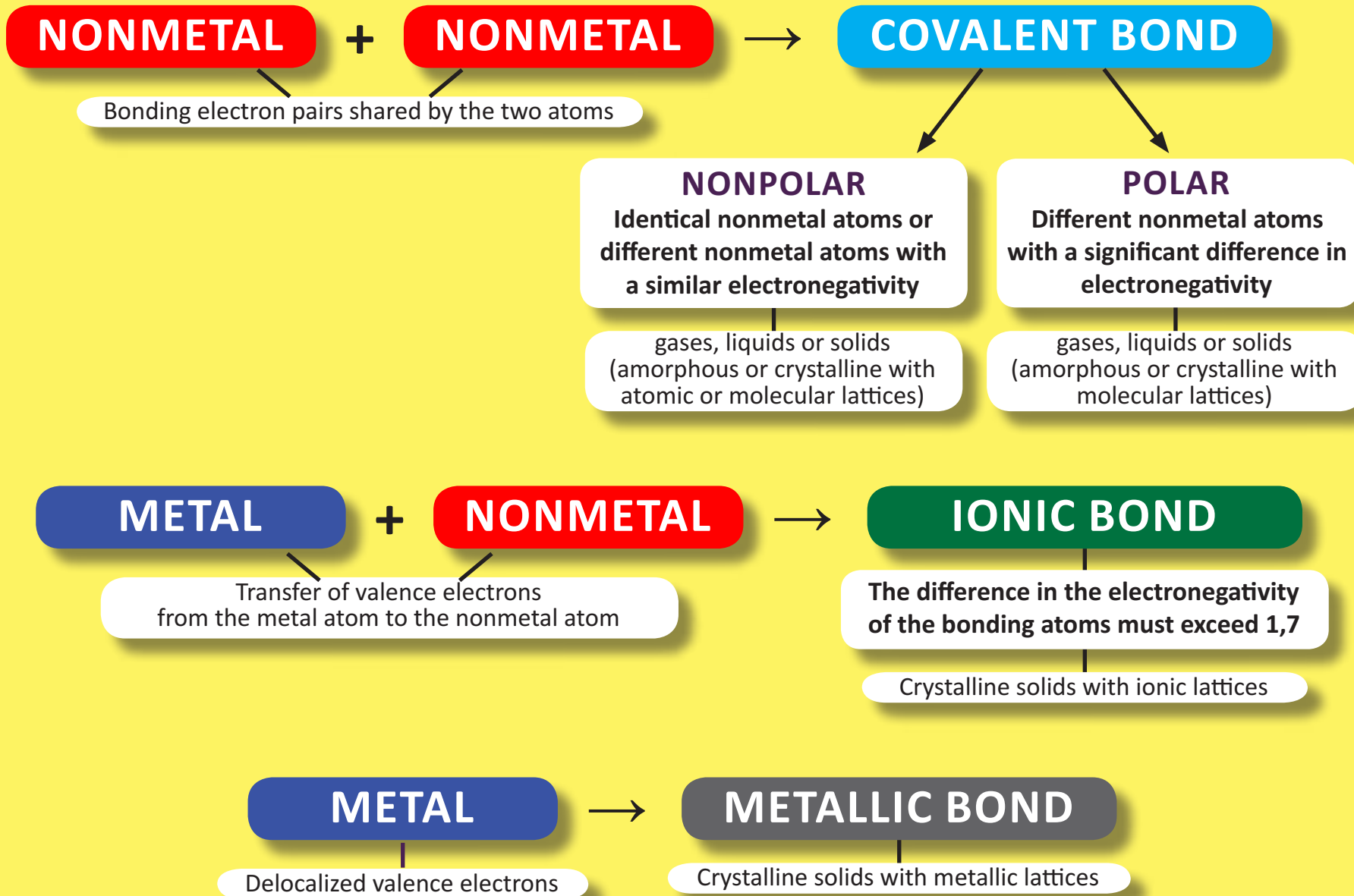
KEY POINTS:

- ▶ **METALLIC BOND** is formed between many identical metal atoms forming metallic lattices.
- ▶ All atoms in a metallic lattice share their valence electrons. These electrons are free to move inside the lattice, i.e. they are **delocalized**. Metal crystal is held together by strong electrostatic forces of attraction acting between the positively charged atomic nuclei and the negatively charged delocalized electrons.
- ▶ Metals are shiny crystalline substances. They conduct electricity and heat. Metals are low volatile solid crystalline substances with high melting points.

CHEMICAL BONDING SUMMARY:

- ▶ **Atoms (same or different) can bond to each other to form pure elements or chemical compounds.**
- ▶ **The type of bonding depends on the identity of the bonding atoms.**
- ▶ **Usually the atoms of two (same or different) nonmetals are covalently bonded. Bonds are polar or nonpolar depending on the electronegativity of the bonding atoms. Molecules with polar bonds are polar or nonpolar depending on their shape.**
- ▶ **The structure of nonmetals is atomic or molecular. If solid, they are amorphous or crystalline with atomic or molecular lattices.**
- ▶ **The structure of the covalent compounds is molecular. If solid, they are amorphous or crystalline with molecular lattices.**
- ▶ **If the difference in the electronegativity of the two bonding atoms is greater than 1.7, the bond is ionic (usually when a metal atom bonds to a nonmetal atom). Ionic compounds are solid substances with ionic crystal lattices. Ionic compounds are brittle. They are insulators.**
- ▶ **Metal atoms form metallic crystal lattices. All atoms in a metallic lattice share their valence electrons. Metals are plastic (malleable and ductile). They are shiny substances with metallic lustre. They conduct heat and electricity.**

TO REMEMBER:



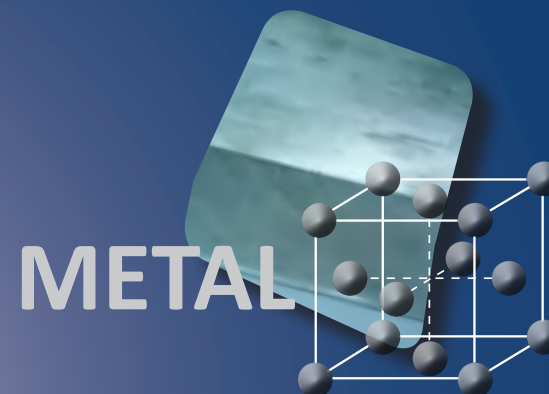
CAN YOU ANSWER THESE QUESTIONS ?

1. What is chemical bond?
2. What types of chemical bonding do you know?
3. Why is diamond so hard?
4. Why are most of the simple solid covalent substances insulators?
5. Chlorine and hydrogen molecules (Cl_2 and H_2) are nonpolar but hydrogen chloride molecules HCl are polar. Why?
6. Why are water molecules H_2O polar but carbon dioxide molecules CO_2 – nonpolar?
7. What is the difference between an ionic crystal lattice and a metallic crystal lattice?
8. Crystals of table salt NaCl are made up of Na^+ and Cl^- ions but in solid state this compound is an insulator. Why?
9. Why do metals conduct electricity?
10. Ionic compounds can not be used to make thin foils. Why?

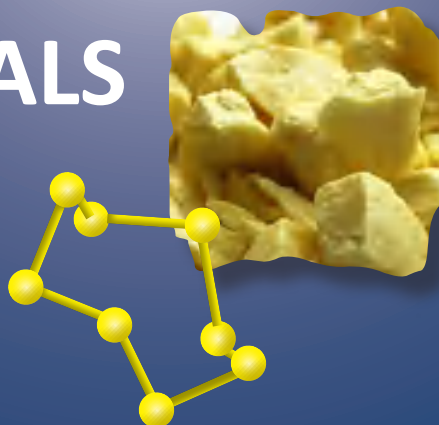
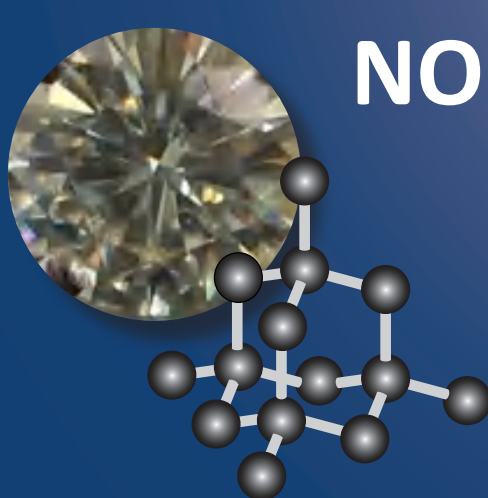
● METALS, NONMETALS AND THEIR COMPOUNDS

KEY TOPICS

1. What are metals and what are nonmetals?
2. What reactions are typical of metals and what – of nonmetals?
3. What are basic oxides and what are acidic oxides?
4. What are bases and what are acids?



NONMETALS



KEY WORDS

- Metals
- Nonmetals
- Basic oxides
- Acidic oxides
- Amphoteric oxides
- Bases
- Acids
- Amphoteric hydroxides

METALS vs. NONMETALS

All pure elements are made up of identical atoms, i.e. of the atoms of one chemical element. For example, sodium is built up of sodium atoms Na, sulfur – of sulfur atoms S, chlorine – of chlorine atoms Cl, diamond – of carbon atoms C, etc. Each pure element is unique. It is characterised by its physical and chemical properties. But, generally, elements are classified as **METALS** or **NONMETALS** depending on their properties, i.e. on the structure of the outer valence shells of their atoms.

METALS are odourless shiny (with metallic lustre) solid crystalline (except the liquid mercury Hg) substances. They are malleable and ductile. The metallic thin folios and wires are well known products. Metals conduct heat and electricity. More than 75 % of the known chemical elements are metals. Their properties are similar.

METALS

*crystalline solids
shiny
odourless
malleable
ductile
conduct heat
conduct electricity*

NONMETALS are gases (O_2 , H_2 , Cl_2 , etc.) and solids – crystalline

NONMETALS

*solid or gaseous
odourless or with a specific odour
colourless or coloured
insulators (electrical and thermal)*

(diamond, I_2 , sulfur S_8) or amorphous (coal, amorphous allotrope of sulfur). Only bromine Br_2 is liquid. Some have a specific odour (Cl_2). Hydrogen H_2 , oxygen O_2 , nitrogen N_2 are colourless but

chlorine Cl_2 is yellow-green, iodine I_2 is violet-black, sulfur S is yellow, etc. Generally, nonmetals do not conduct heat and electricity. An exception is graphite. Nonmetals are much less than metals but their properties are various.

The periodic table summarises all known chemical elements. The virtual line linking boron **B** ($Z = 5$) and astatine **At** ($Z = 85$) is the „border“ between metals and nonmetals. Metals are located to its left and nonmetals – to its right. The elements located next to the „border“ line generally are not typical metals or nonmetals (they are called metalloids) and they display some unusual properties. Most typical are silicon Si, germanium Ge.

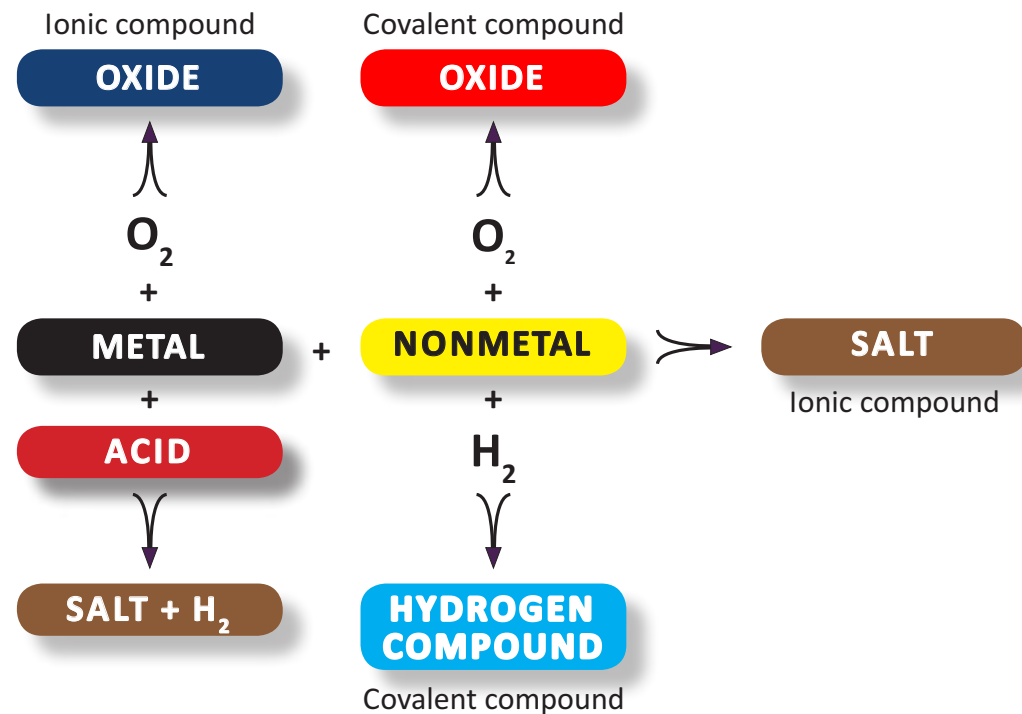
													<i>More nonmetallic elements</i> →					18 VIIIA	
													13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	2 He HELIUM 4,00	
1 H HYDROGEN 1,0079												5 B BORON 10,81	6 C CARBON 12,01	7 N NITROGEN 14,01	8 O OXYGEN 16,00	9 F FLUORINE 19,00	10 Ne NEON 20,18		
3 Li LITHIUM 6,94	4 Be BERYLLIUM 9,01											13 Al ALUMIN(I)UM 26,98	14 Si SILICON 28,09	15 P PHOSPHORUS 30,97	16 S SULFUR 32,06	17 Cl CHLORINE 35,45	18 Ar ARGON 39,95		
11 Na SODIUM 22,99	12 Mg MAGNESIUM 24,31	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB					18 Ar ARGON 39,95			
19 K POTASSIUM 39,10	20 Ca CALCIUM 40,08	21 Sc SCANDIUM 44,96	22 Ti TITANIUM 47,87	23 V VANADIUM 50,94	24 Cr CHROMIUM 52,00	25 Mn MANGANESE 54,94	26 Fe IRON 55,85	27 Co COBALT 58,93	28 Ni NICKEL 58,69	29 Cu COPPER 63,55	30 Zn ZINC [65,38]	31 Ga GALLIUM 69,72	32 Ge GERMANIUM 72,63	33 As ARSENIC 74,92	34 Se SELENIUM 78,96	35 Br BROMINE 79,90	36 Kr KRYPTON [83,80]		
37 Rb RUBIDIUM 85,47	38 Sr STRONTIUM 87,62	39 Y YTTRIUM 88,91	40 Zr ZIRCONIUM 91,22	41 Nb NI OBIUM 92,91	42 Mo MOLYBDENUM 95,96	43 Tc TECHNETIUM (98)	44 Ru RUTHENIUM 101,1	45 Rh RHODIUM 102,9	46 Pd PALLADIUM 106,4	47 Ag SILVER 107,9	48 Cd CADMIUM 112,4	49 In INDIUM 114,8	50 Sn TIN 118,7	51 Sb ANTIMONY 121,8	52 Te TELLURIUM 127,,8	53 I IODINE 126,9	54 Xe XENON [131,3]		
55 Cs C(A)ESIUM 132,9	56 Ba BARIUM 137,3	57 La LANTHANUM 138,9	72 Hf HAFNIUM 178,5	73 Ta TANTALUM 180,9	74 W TUNGSTEN 183,8	75 Re RHENIUM 186,2	76 Os OSMIUM [190,2]	77 Ir IRIDIUM [192,2]	78 Pt PLATINUM [195,1]	79 Au GOLD 197,0	80 Hg MERCURY 200,6	81 Tl THALLIUM 204,3	82 Pb LEAD 207,2	83 Bi BISMUTH 209,0	84 Po POLONIUM [(209)]	85 At ASTATINE [(210)]	86 Rn RADON (222)		
87 Fr FRANCIUM (223)	88 Ra RADIUM (226)	89 Ac ACTINIUM (227)	104 Rf RUTHERFORDIUM (261)	105 Db DUBNIUM (262)	106 Sg SEABORGIUM (266)	107 Bh BOHRIUM (264)	108 Hs HASSIUM (277)	109 Mt MEITNERIUM (268)	110 Ds DARMSTADIUM (281)	111 Rg ROENTGENIUM (272)	112 Cn COPERNICIUM (285)	113 Nh NIHONIUM [(286)]	114 Fr FLEROVIUM [(289)]	115 Mc MOSCOVIUM (290)	116 Lv LIVERMORIUM (293)	117 Ts TENNESSINE (294)	118 Og OGANESSON (294)		
													<i>More metallic elements</i> ←						

Metallic elements are less electronegative elements than nonmetallic elements, i.e. they easily lose their valence electrons and transform into positive ions (Na^+ , K^+ , Mg^{2+} , Ca^{2+} , etc.). The most active metals are **alkali metals** 1 (IA) group and **alkaline earth metals** 2 (IIA) group. Cesium Cs is the least electronegative and the most active metal found in nature. Aluminum Al 3 (IIIA) group is also a metallic element but it displays some unusual properties. The elements of the secondary B groups (3th – 12th group), e.g. iron **Fe**, zinc **Zn**, copper **Cu**, gold **Au**, silver **Ag** etc., are known as *transition metals*. All metals (except Hg) are solid crystalline substances with metallic lattices.

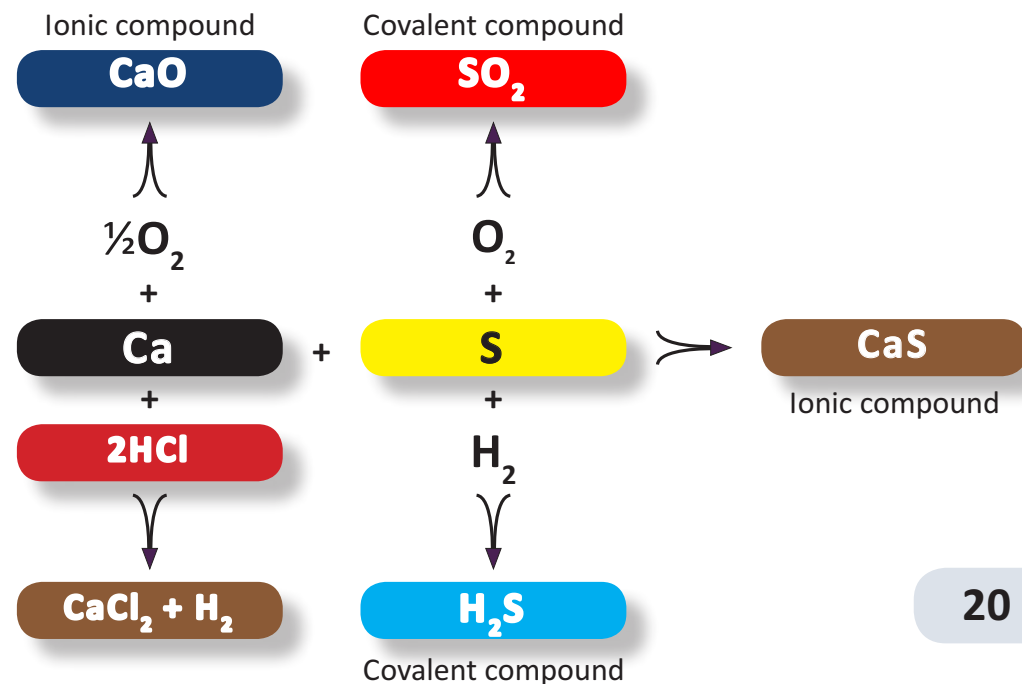
Nonmetallic elements are elements with a relatively high electronegativity. They attract the bonding electron pairs and form negatively charged ions (Cl^- , S^{2-} , etc.). The most electronegative element is fluorine **F** and it is the most nonmetallic element.

Typical of metals are the reactions with oxygen O_2 , nonmetals (Cl_2 , Br_2 , S) and acids (HCl , H_2SO_4 , HNO_3). Nonmetals also react with oxygen and another typical reaction is their interaction with hydrogen.

Metals form **basic oxides**. They are ionic compounds. Nonmetals form **acidic oxides**. They are covalent nonpolar (CO_2) or polar compounds (H_2O , NO , SO_2). Salts are ionic compounds.



As an example:



BASIC OXIDES vs. ACIDIC OXIDES

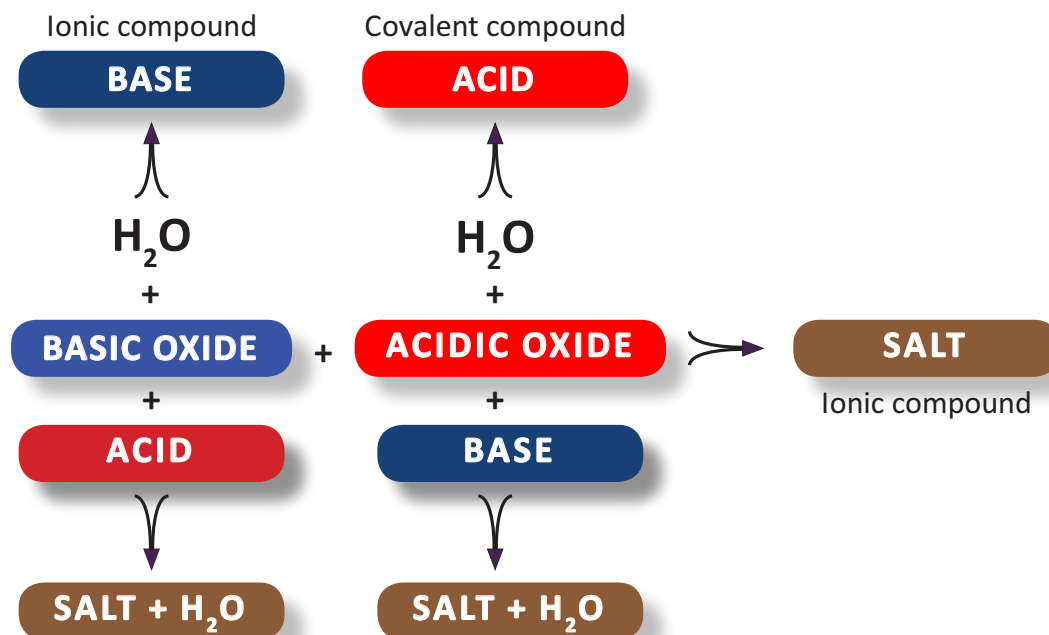
Oxides of metals and oxides of nonmetals have completely opposite characters. Oxides of **metals** are **basic oxides** – if soluble, they react with water and transform into **bases** ($\text{Na}_2\text{O} + \text{H}_2\text{O} \rightarrow 2\text{NaOH}$). Oxides of **nonmetals** are **acidic oxides** – if soluble, they also react with water but transform into **acids** ($\text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4$).

Typical reactions of **basic oxides** (besides the reaction with water) are the interactions with acidic oxides and acids. Salts are produced in both reactions. In the reaction with an acid water is also formed. This set of chemical reactions determines the **basic character** of the **oxides of metals**.

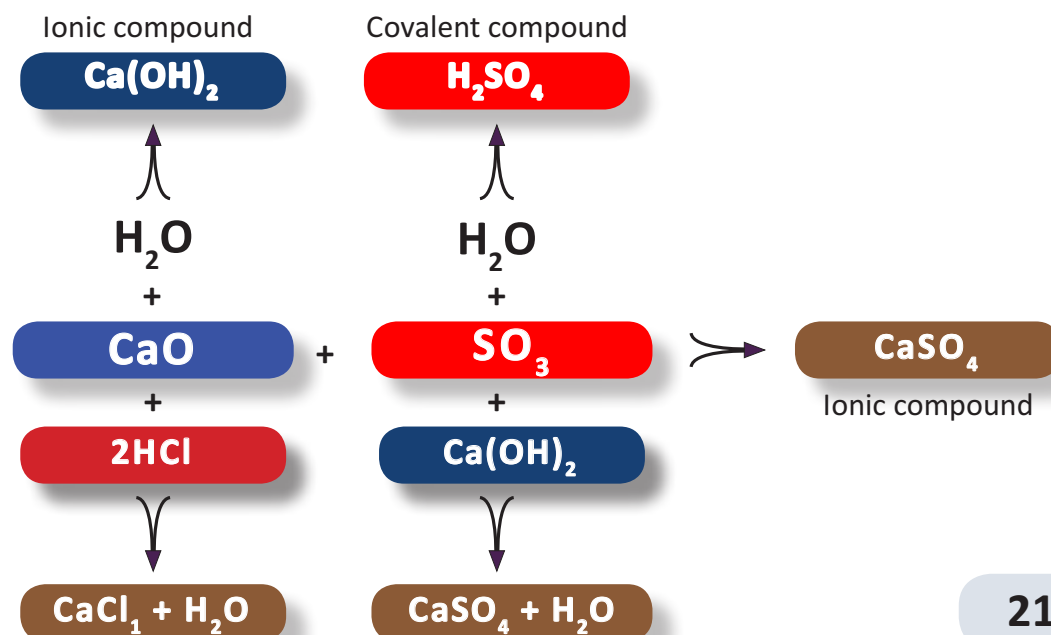
Typical reaction of **acidic oxides** (besides the interactions with water and basic oxides) is the reaction with bases. The products are salts and water. This set of chemical reactions determines the **acidic character** of the **oxides of nonmetals**.

Dialuminum trioxide Al_2O_3 react with both acids and strong bases – this is an **amphoteric oxide**.

Some oxides do not react either with bases or with acids. They do not react with water too. They are **neutral oxides**. CO , N_2O , NO are neutral oxides.

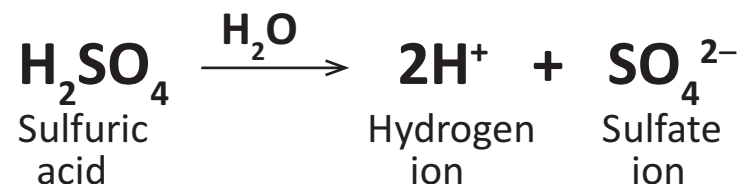
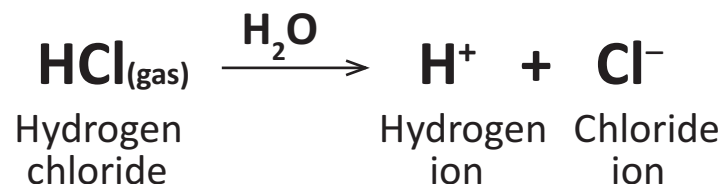


As an example:



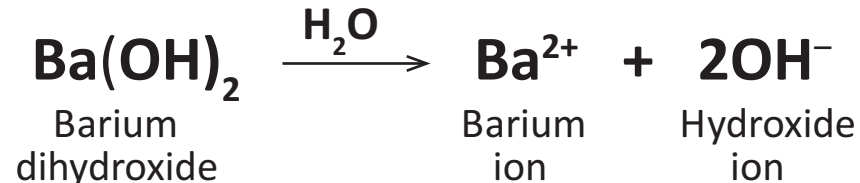
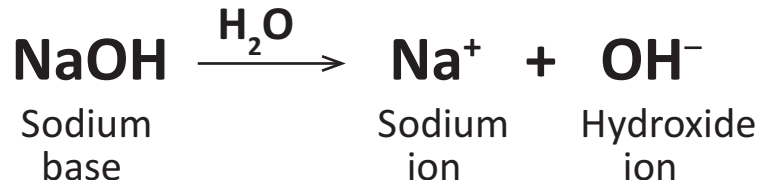
ACIDS vs. BASES

Acids and **bases** are two important classes of chemical compounds. Soluble acids and bases dissociate in water. Acids liberate positive hydrogen ions (H^+)* and negative acidic ions (Cl^- , S^{2-} , SO_4^{2-} , NO_3^-).



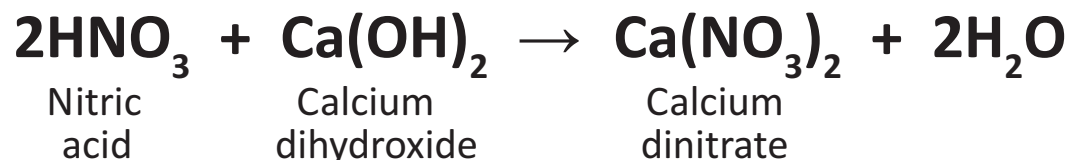
In the presence of H^+ ions litmus turns **red** and phenolphthalein is colourless. For all aqueous solutions of acids **pH** < 7**.

Bases liberate positive metallic ions (Na^+ , K^+ , Mg^{2+} , Ca^{2+}) and negative hydroxide ions OH^- .



In the presence of OH^- ions litmus turns **blue** and phenolphthalein is **pink-red**. For all aqueous solutions of bases **pH > 7**.

The reaction of an acid with a base is called **neutralisation**. A salt and water are produced.



* In aqueous solutions H^+ ions bond to a water molecule and form hydronium ions H_3O^+ .

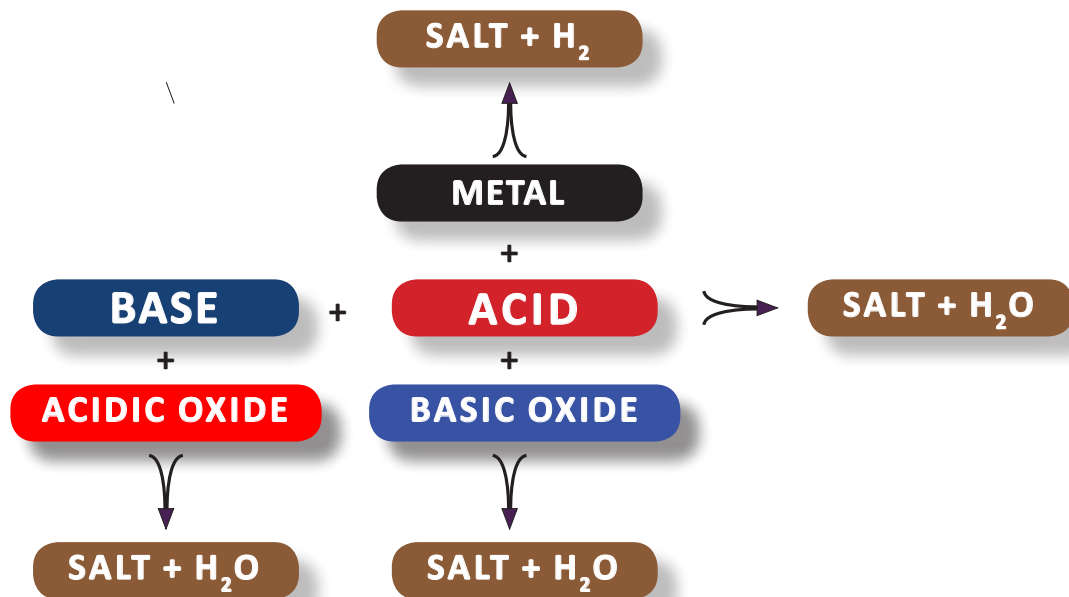
** **pH** is a measure of the acidity or the basicity of the solutions – its value is related to the amount of H^+ ions in the solution.

Typical reactions of bases, besides the reaction of neutralisation, is the interaction with acidic oxides (SO_3 , CO_2). The products are a salt and water.

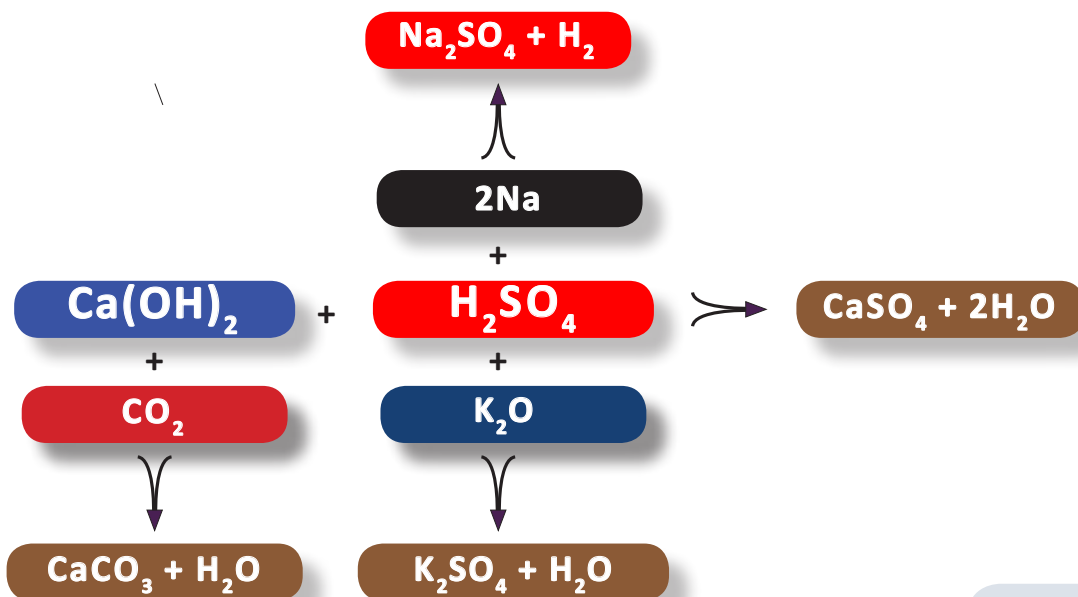
Oppositely, acids react with basic oxides (Na_2O , K_2O , CaO , BaO , etc.) to produce a salt and water. A typical reaction of acids is also their interaction with active metals (Na , K , Ca , Ba , Zn , etc.). Also a salt forms and hydrogen is liberated. Less active metals (copper, Cu , silver Ag , gold Au) do not react with diluted acids.

The concentrated nitric acid HNO_3 and the concentrated sulfuric acids H_2SO_4 manifest some specific properties. In water only a few of the acids molecules dissociate and the amount of H^+ ions is too small. The concentrated nitric and sulfuric acids are toxic and extremely dangerous. They burn up the skin, the cloths, the plastics. When working with them it is obligatory to respect all recommended safety precautions.

Aluminum trihydroxide $\text{Al}(\text{OH})_3$ reacts with both acids and strong bases – this is an **amphoteric hydroxide**.



As an example:



CAN YOU ANSWER THESE QUESTIONS ?

1. Why are some elements metallic but other – nonmetallic?
2. Why are metals conductors of heat and electricity but nonmetals are insulators?
3. Why are metals ductile and malleable?
4. Why is quicklime CaO a basic oxide but sulfur trioxide SO_3 – an acidic oxide?
5. Which of the oxides Na_2O , CaO , CO_2 , SO_2 are ionic compounds and which – covalent substances?
6. Why can SO_3 pumped in the atmosphere cause acid rains?
7. Both potassium base KOH and nitric acid HNO_3 are soluble substances. What ions are present in their aqueous solutions?
8. What is the colour of litmus in an aqueous solution of sodium base NaOH and in hydrochloric acid HCl ?
9. What is reaction of neutralisation?
10. What is the salt NaCl made of?

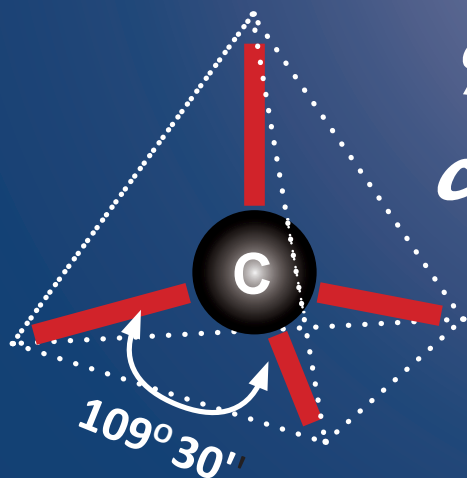
● ORGANIC COMPOUNDS

KEY TOPICS

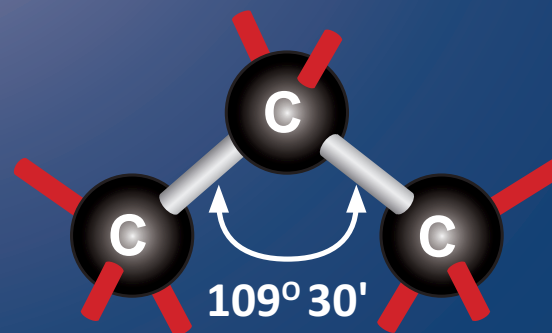
1. Why are there so many different organic compounds?
2. What is the difference between saturated and unsaturated hydrocarbons?
3. Are alcohols, aldehydes, ketones and carboxylic acids reactive compounds? Why?
4. What is CHONPS?
5. What compounds are the main sources of energy for man?

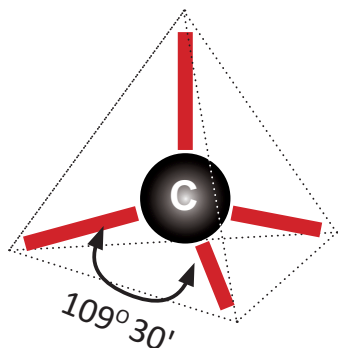
KEY WORDS

- Carbon chains
- Hydrocarbons
- Alcohols and phenols
- Aldehydes and ketones
- Carboxylic acids
- Amino acids
- Carbohydrates
- Fats
- Proteins



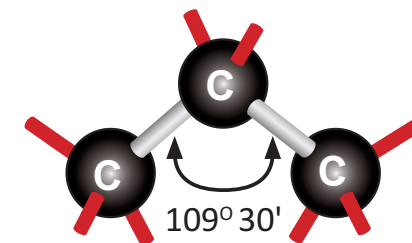
*The amazing
carbon atom*





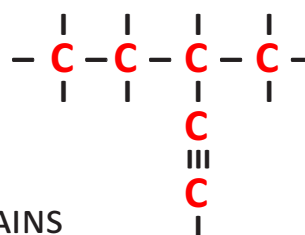
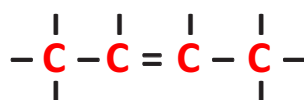
THE TETRAVALENT
CARBON ATOM

ORGANIC COMPOUNDS are all compounds of carbon except CO_2 , H_2CO_3 and its salts and a few others compounds as their properties are different compared to the properties of organic compounds. Methane CH_4 is the simplest organic compound. It and its derivatives (e.g. CH_3Cl , CCl_4 , CH_3OH , HCHO , HCOOH , etc.) are organic compounds with one carbon atom in their molecules. Generally, organic compounds have two or more (even millions) carbon atoms bonded to one another and forming long straight

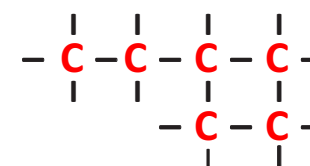


3-CARBON ATOMS CHAIN

or branched, open or closed chains. This particular carbon atoms property is called **CATENATION** (self-linking). The carbon chains are the backbone of each organic compound. The carbon atoms of these „skeleton“ are always tetravalent.



STRAIGHT AND BRANCHED OPEN CARBON CHAINS

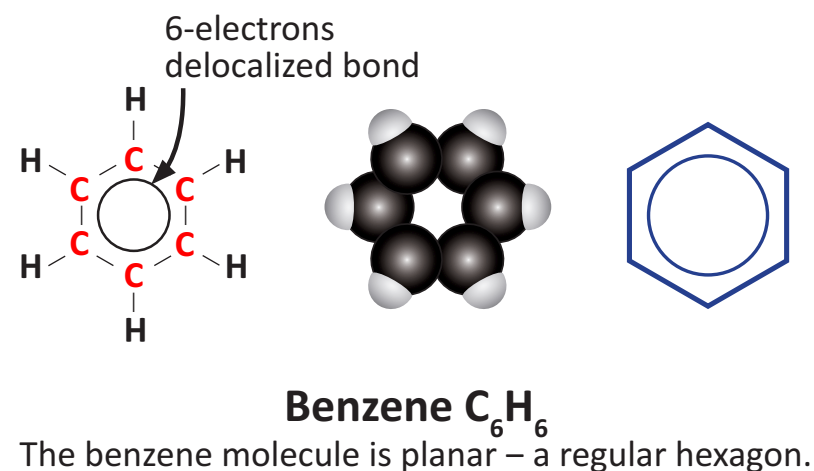
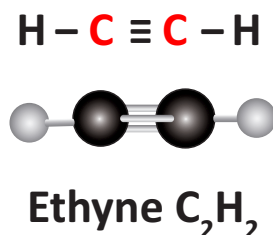
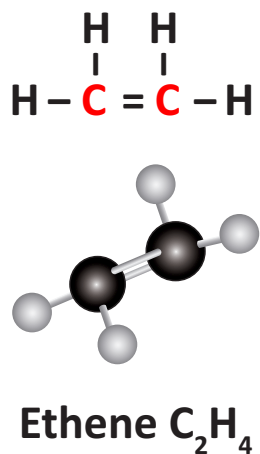
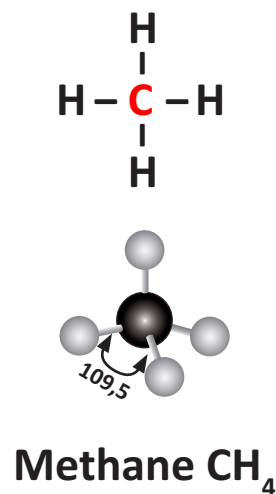


4-ATOMIC RING BONDED
TO A 2-ATOMIC BRANCH

Carbon atoms chemically link to other atoms, more often hydrogen **H**, halogens (**Cl**, **Br**, etc.), oxygen **O**, nitrogen **N**, phosphorus **P**, sulfur **S** and other. Carbon, hydrogen, oxygen, nitrogen, sulfur and phosphorus are considered as the elements of life and the abbreviation **CHONPS** is sometimes used to designate them.

VARIETY OF ORGANIC COMPOUNDS

The variety of organic compounds is enormous (they are millions) but depending on their composition and structure many of them exhibit similar properties and are grouped into classes. The simplest organic compounds are **HYDROCARBONS**. They are made up of carbon and hydrogen atoms only. The most important groups (classes) of hydrocarbons are **alkanes** (with single bonded carbon atoms only), **alkenes** (with at least one double carbon-carbon bond), **alkynes** (with at least one triple carbon-carbon bond), **arenes** (with aromatic rings of 6 carbon atoms). The simplest representatives of these classes of hydrocarbons are methane CH_4 , ethene C_2H_4 , ethyne C_2H_2 and benzene C_6H_6 .



The straight line alkanes, alkenes and alkynes form **homologous series** with general formulae – $\text{C}_n\text{H}_{2n+2}$ for alkanes, C_nH_{2n} for alkenes and $\text{C}_n\text{H}_{2n-2}$ for alkynes.

The first four homologues of the straight hydrocarbons homologous series are known by their common names (e.g. methane CH_4 , ethane C_2H_6 , propane C_3H_8 and butane C_4H_{10}). The names of the straight chain hydrocarbons with 5 and more carbon atoms are formed from the root of the Greek name of the numeral equal to the number of carbon atoms in the molecules and a suffix – „ane“ for alkanes, „ene“ for alkenes and „yne“ for alkynes. The place of the multiple bonds (double or triple) is indicated by the number of the first double or triple bonded carbon atom. The numbering of the carbon atoms starts from the nearest to the double or triple bond chain end.



C_5H_{12} **pentane**

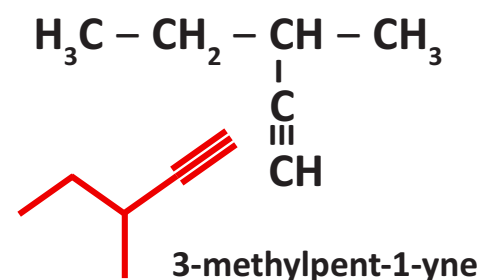


C_6H_{12} **hex-2-ene**

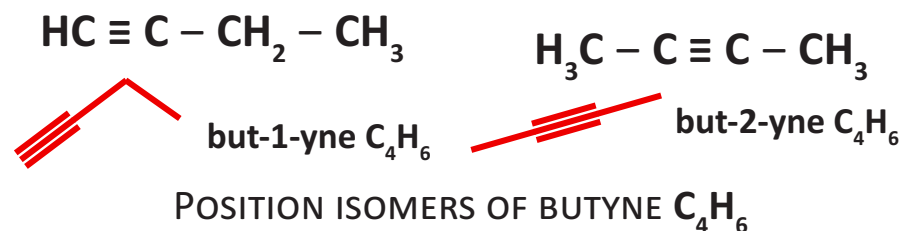


C_7H_{12} **hept-3-yne**

The names of hydrocarbons with branched chains are composed of the name of the hydrocarbon with the same straight carbon chain as the longest straight carbon chain of the molecule and the names of the branches preceded by the numbers of the carbon atoms to which they are bonded.

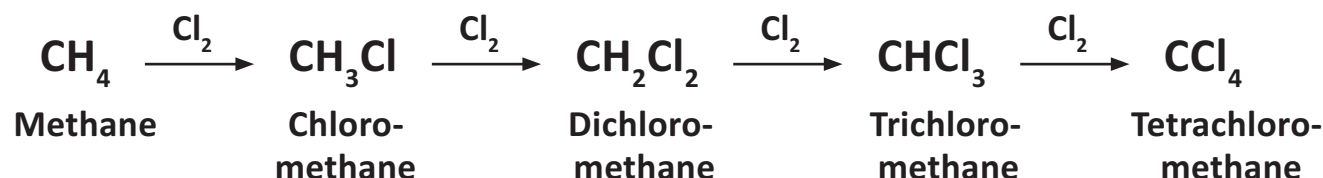


Alkanes with four and more carbon atoms have **chain isomers** (e.g. butane C_4H_{10} and methylpropane). Hydrocarbons with multiple bonds have also chain isomers (e.g. 3-methylpent-1-yne (above) is a chain isomer of hex-1-yne) but **position isomers** are also possible. Butene C_4H_8 and butyne C_4H_6 are the simplest hydrocarbons with position isomers.



REACTIVITY OF HYDROCARBONS

Hydrocarbons are covalent nonpolar compounds. Alkanes are saturated hydrocarbons and they are not very reactive compounds. Typical are the **substitution reactions** (one or more hydrogen atoms are replaced by other atoms or atomic groups), e.g. the halogenation of methane CH_4 (the gas is exposed to sunlight). The products are **derivatives of hydrocarbons**.

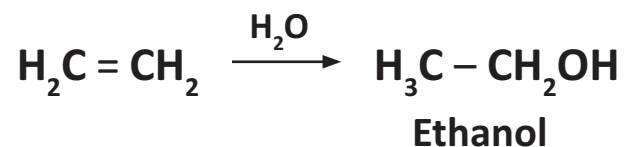


Alkenes and alkynes are unsaturated hydrocarbons. Their double or triple carbon-carbon bonds can break down and hydrogen H_2 , halogens (Cl_2 , Br_2), hydrogen halides (HCl , HBr), water and other molecules can be added to their molecules. These reactions are **addition reactions**. For example:



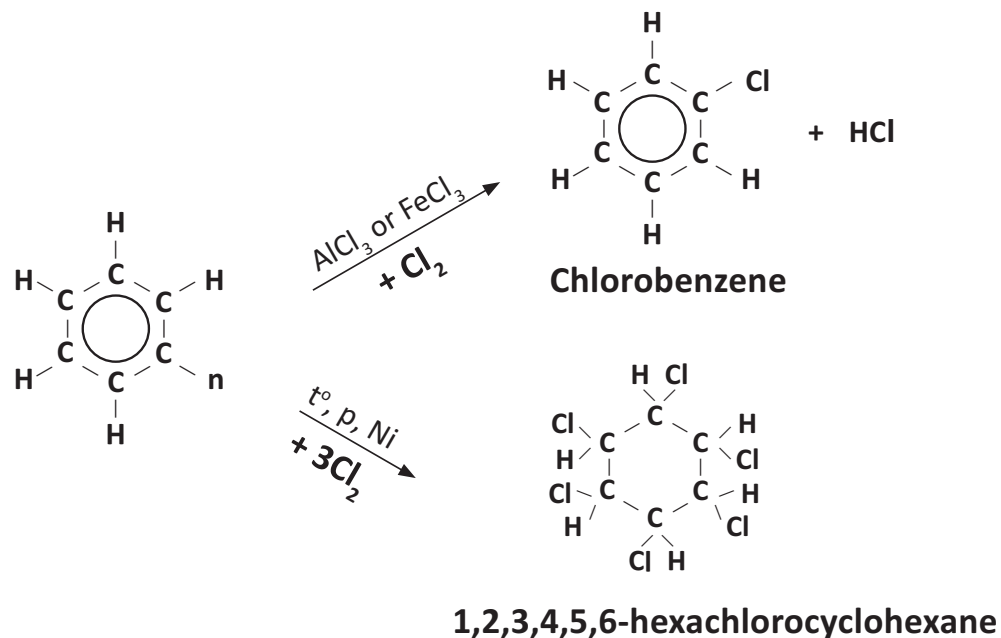
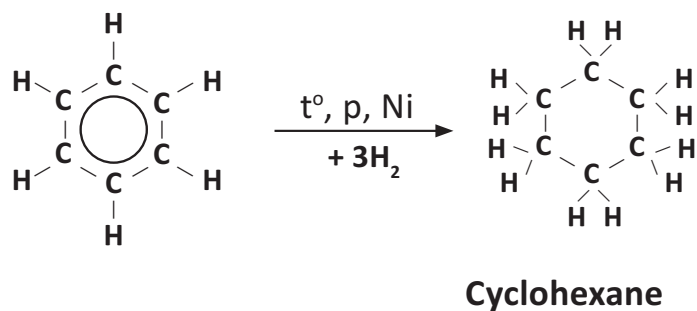
The reaction of discoloration of bromine water is a test for alkenes and alkynes !





The products of the reactions of addition of halogens, hydrogen halides or water (the reaction is called *hydration*) are **derivative of hydrocarbons**.

Benzene C_6H_6 (the simplest arene) also takes part in addition and substitution reactions. Under special conditions it adds 3 molecules of hydrogen and transforms into cyclohexane. Benzene reacts also with halogens and depending on the reaction conditions a substitution or an addition reaction undergoes.



A well known chemical reaction of hydrocarbons is their **combustion**. Natural gas and oil are fuels composed mainly of hydrocarbons. The products of the combustion of hydrocarbons are carbon dioxide CO_2 and water and a significant amount of energy is released. For example:



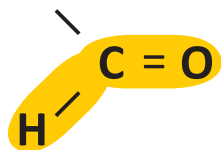
The combustion of fossil fuels is a major source of atmospheric CO_2 – a prominent greenhouse gas.

HYDROCARBON DERIVATIVES

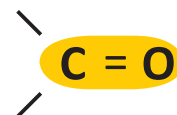
HYDROCARBON DERIVATIVES are organic compounds regarded as formed from hydrocarbons in whose molecules one or more hydrogen atoms have been replaced by other atoms or atomic groups. The simplest derivatives of hydrocarbons are the halogen derivatives (CH_3Cl , $\text{C}_2\text{H}_5\text{Br}$, etc.). Alcohols, aldehydes, ketones, carboxylic acids, amines and amino acids are all derivatives of hydrocarbons. Their properties depend on the **functional groups** bonded to one or more carbon atoms of their carbon chains. The names of the different groups of derivatives of hydrocarbons originate from the names of the functional group in their molecules.



HYDROXY GROUP
HYDROXY DERIVATIVE
ALCOHOLS and PHENOLS
 $\text{C}_2\text{H}_5\text{OH}$, $\text{C}_6\text{H}_5\text{OH}$



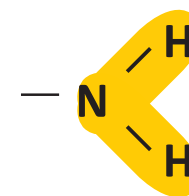
ALDEHYDE GROUP
ALDEHYDES
 CH_3CHO



KETONE GROUP
KETONES
 CH_3COCH_3



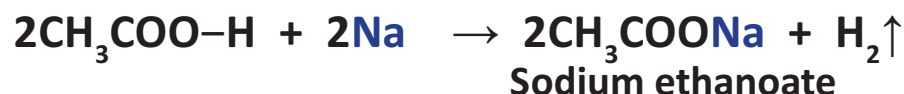
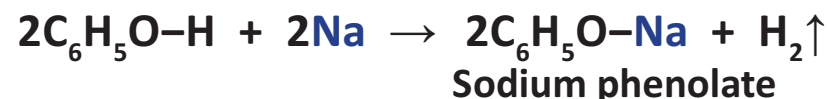
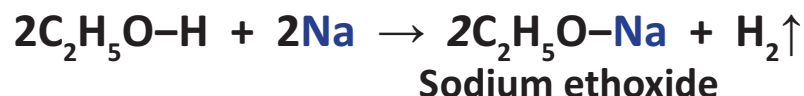
CARBOXYL GROUP
CARBOXYLIC ACIDS
 CH_3COOH



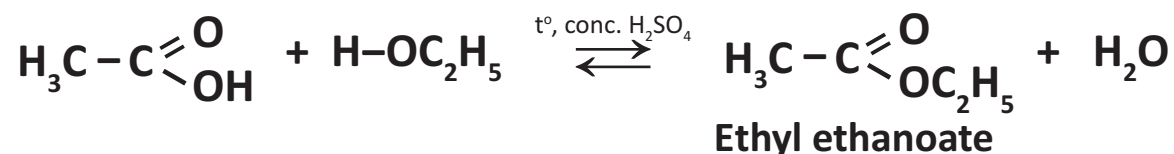
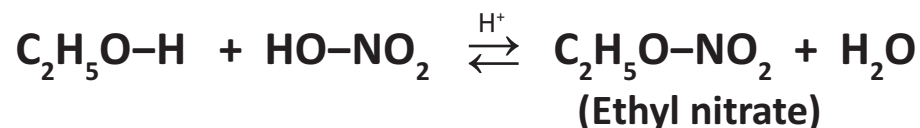
AMINO GROUP
AMINES
 CH_3NH_2

Derivatives of hydrocarbons react with *inorganic* and *organic* compounds.

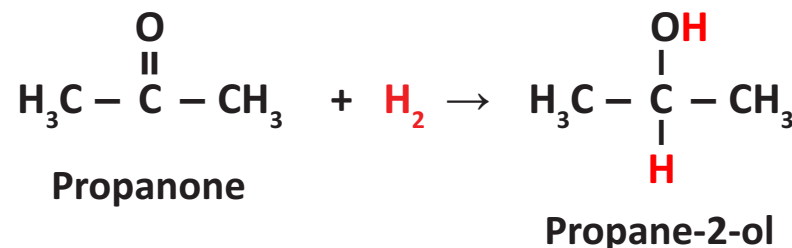
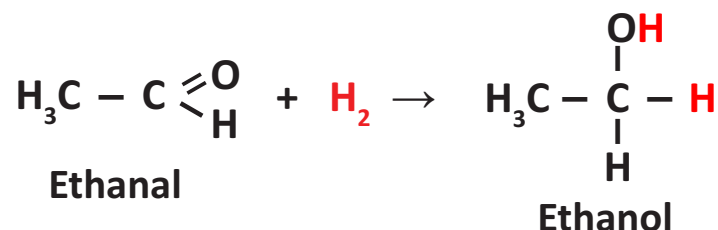
- **REACTION WITH ACTIVE METALS.** Alcohols, phenols and carboxylic acids have one or more hydroxy groups –OH. The O ← H bond is a polar covalent bond. The hydrogen atom is mobile and it can be replaced by atoms of active metals.



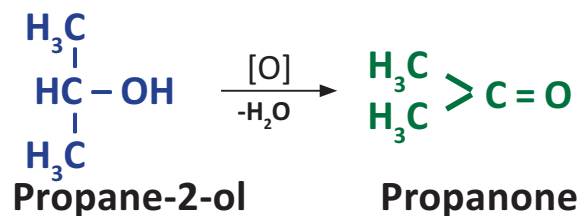
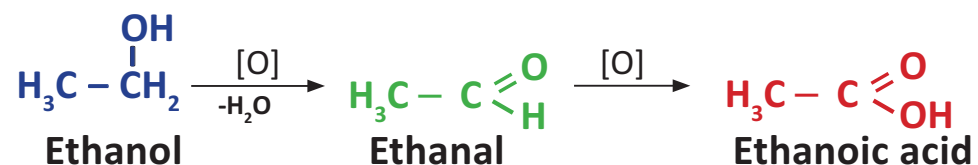
- **REACTION OF ESTERIFICATION.** This is a reaction of a hydroxy derivative with an oxy-acid (inorganic or organic). It is a slow, molecular and reversible reaction, yielding an **ester** and water. For example:



- **ADDITION OF HYDROGEN H_2 .** Derivatives of hydrocarbons with double bonded carbon and oxygen atoms ($>\text{C}=\text{O}$) add hydrogen molecules. The products are alcohols with the same number of carbon atoms. This reaction is typical of aldehydes and ketones. For example:



- **OXIDATION**. Alcohols, aldehydes and ketones are oxidised under special conditions (more often under heating and in the presence of catalysts*). Primary alcohols transform into aldehydes, secondary alcohols – into ketones. Aldehydes are oxidised to produce carboxylic acids.



Another reaction of hydrocarbon derivatives with oxygen is their **combustion**. Methanol CH_3OH and ethanol $\text{C}_2\text{H}_5\text{OH}$ are fuels – a considerable amount of energy is liberated. The products are carbon dioxide CO_2 and water.



Both are renewable **biofuels**. The use of methanol and ethanol as fuels contributes to the reduction of greenhouse gases emissions.

* **Catalysts** are substances that accelerate chemical reactions without themselves being consumed.

** $[\text{O}]$ indicates oxygen from an oxidising agent. You will become familiar with oxidation-reduction reactions in chap. 22.

ORGANIC COMPOUNDS IN LIVING NATURE

Many organic compounds are essential for maintaining life in plants, animals and humans. Carbohydrates, fats and proteins are absolutely indispensable for living nature.

CARBOHYDRATES are the most abundant organic compounds in living organisms. Their general formula is $C_n(H_2O)_m$. Some short chains carbohydrates are sweet and are known as saccharides.

GLUCOSE $C_6H_{12}O_6$ is one of the simplest carbohydrates. It is a **monosaccharide**.

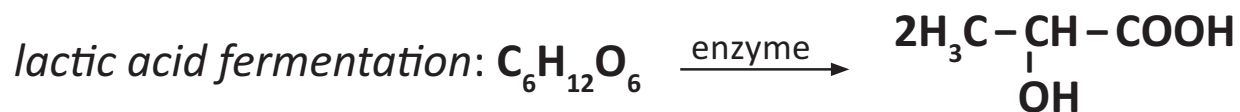
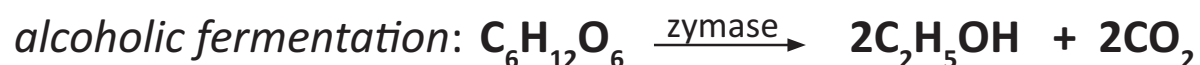
SACCHAROSE $C_{12}H_{22}O_{11}$ (the sugar) is a **disaccharide** – two monosaccharides residues (of α -D-glucose and β -D-fructose) are bonded by a **glycosidic linkage**.

Glucose and saccharose are polyhydric alcohol.

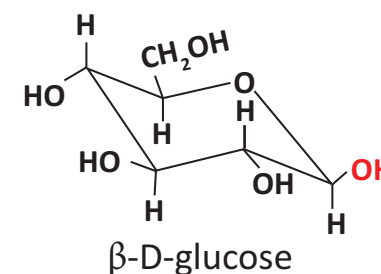
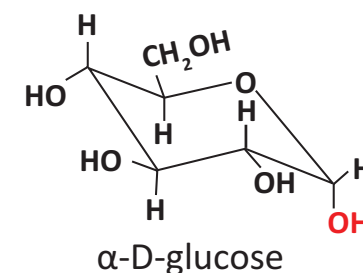
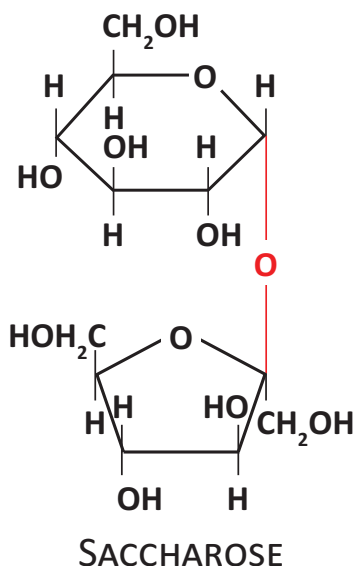
Glucose is an energy resource for the human body. It reacts with oxygen and transforms into carbon dioxide and water liberating a significant amount of energy.



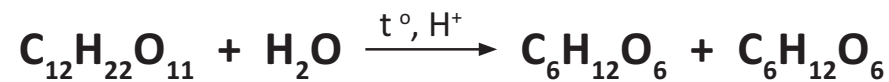
A well known biochemical process is the **fermentation** of glucose. Under the action of specific enzymes it transforms into ethanol C_2H_5OH or lactic acid.



2-hydroxypropanoic acid (lactic acid)

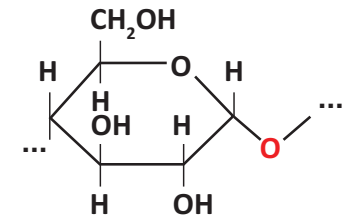


An Important biochemical reaction of saccharose is its **hydrolysis**. Under heating and in the presence of H^+ ions it reacts with water and transforms into α -D-glucose and β -D-fructose (the monosaccharides whose residues build up saccharose molecules).



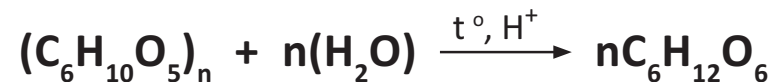
In the human body this process undergoes under the action of the enzyme invertase. The produced α -D-glucose is an energy resource for the body.

Starch and cellulose are **polysaccharides**. **STARCH** ($C_6H_{10}O_5$)_n is a biopolymer built up of α -D-glucose residues. The long chains are straight (amylose) or branched (amylopectine). Most often starch is composed of 20 – 30 % amylose and 70 – 80 % amylopectin.

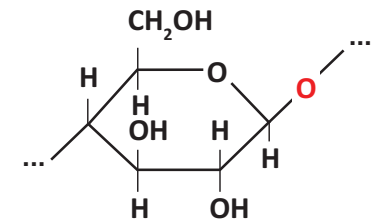


α -D glucose residue

Starch hydrolysis under the action of the enzyme amylaze or in presence of H^+ ions and under heating. The final product is α -D-glucose.

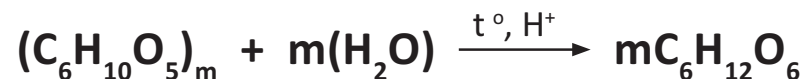


CELLULOSE is a fibrous biopolymer composed of many β -D-glucose residues. Its chemical formula is similar to that of starch – ($C_6H_{10}O_5$)_m. It is a building material for plants. It is not assimilated by the human organism. The cellulose molecules are straight and strong intermolecular forces keep them in bundles. Cellulose does not dissolve in water and may be processed to produce fibres.



β -D glucose residue

The hydrolysis of cellulose is difficult as compared to the hydrolyses of starch. The final product is β -D-glucose.



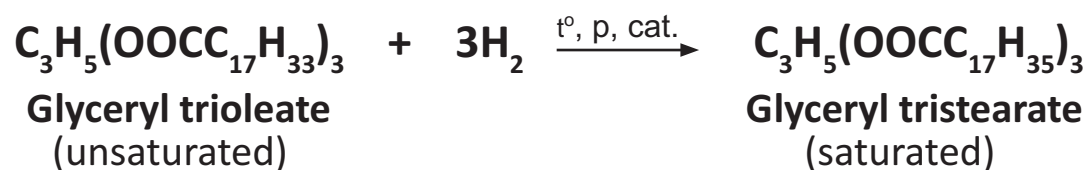
Unlike starch cellulose is not a source energy for humans as our bodies do not synthesise enzymes to hydrolyse this carbohydrate. But cellulose fibres are important for the balanced nutrition.

FATS are also named triglycerides as they are esters of propane-1,2,3-triol (glycerine) $C_3H_5(OH)_3$ and **fatty acids** (saturated or unsaturated carboxylic acids with straight chains of uneven number of carbon atoms (generally, up to 23)). Some of the most important are the fatty acids with 14-18 carbon atoms (including the carbon atom of the COOH group). For example, palmitic acid $C_{15}H_{31}COOH$, stearic acid $C_{17}H_{35}COOH$, oleic acid $C_{17}H_{33}COOH$, etc. Fats containing only saturated fatty acids residues are called saturated fats and fats containing unsaturated fatty acids residues are called unsaturated. Generally, the „good“ for a healthy body fats are the unsaturated fats.

Fats and oils (liquid triglycerides containing unsaturated fatty acids residues) are insoluble in water. They are poor conductors of heat. Natural fats are mixtures of different triglycerides.

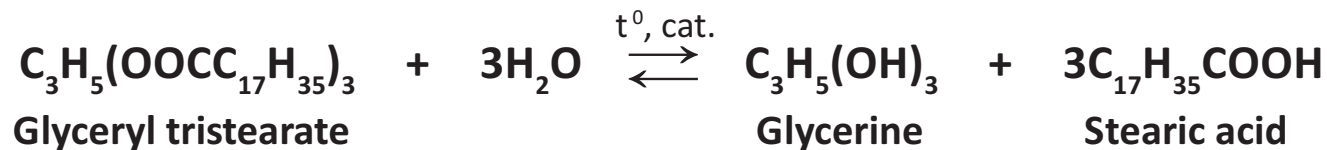
Important chemical processes involving fats and oils are their hydrogenation, hydrolysis and saponification.

The **hydrogenation** (the addition of hydrogen to unsaturated fatty acids residues) transforms the unsaturated triglycerides into saturated triglycerides. For example:



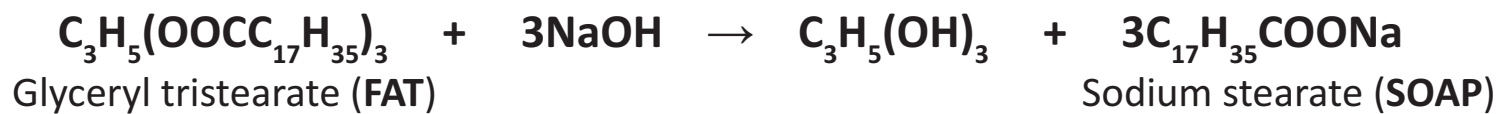
On an industrial scale the hydrogenation of the liquid sunflower oil (or other vegetable oils) is used to produce margarine.

Hydrolysis of fats and oils is also important for the industry process as fatty acids are produced. For example:



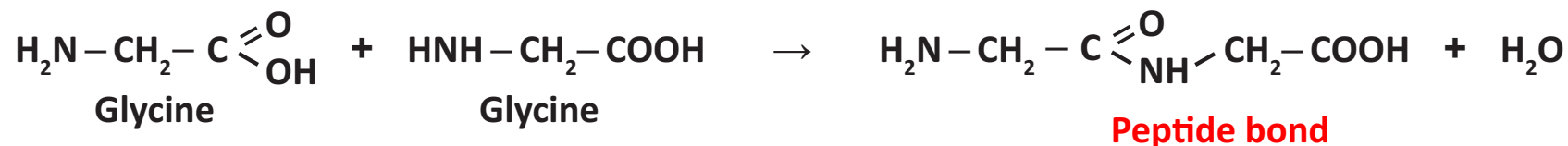
In the human body hydrolysis of fats takes place under the action of the enzyme lipase.

The hydrolysis of fats under heating and in the presence of a strong base (NaOH, KOH, LiOH) is an irreversible reaction known as **saponification**. The products are propane-1,2,3-triol and soaps – salts of fatty acids. For example:

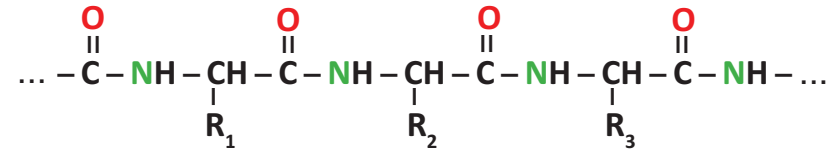


PROTEINS are biopolymers essential to life. They are building blocks of tissues and an important energy resource. Hormones, enzymes, antibodies are proteins. Proteins contain many α -amino acid residues bonded in long polypeptide chains thanks to the capability of α -amino acids to link to one another by peptide bonds.

Amino acids have two functional groups – an amino group $-\text{NH}_2$ and a carboxyl group $-\text{COOH}$. Two α -amino acids (the amino group is bonded to the second carbon atom of the chain) can react producing a dipeptide and liberating water. For example:

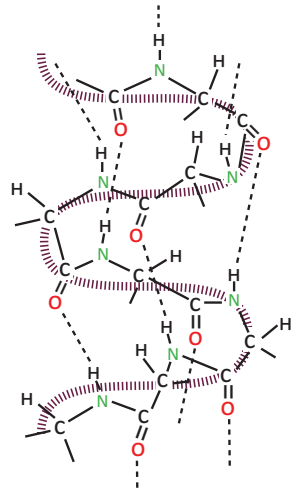


About 20 α -amino acids build up proteins. The type and the sequence of their residues in the long polypeptide chains determine the **primary** structure of proteins. It is unique. The specific folding of the polypeptide chains

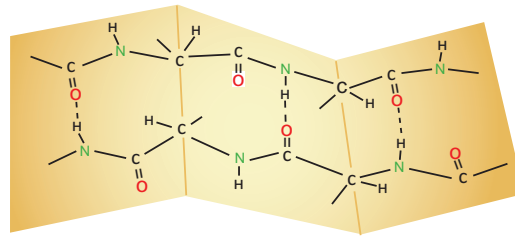


POLYPEPTIDE CHAIN OF A PROTEIN

represents the **secondary** structure of proteins. Many 3D patterns are known but the most common are the α -helix and the β -sheet.



α -helix



β -sheet

SECONDARY STRUCTURES

The final 3D conformation of the whole protein chain is called **tertiary** structure.

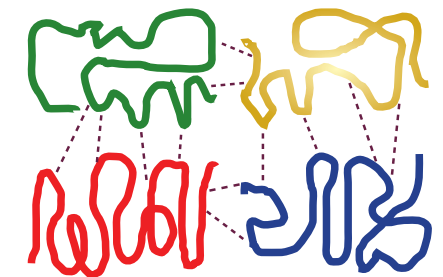
Proteins with more than one polypeptide chain in their molecules have also



TERTIARY STRUCTURE

a **quaternary** structure. This is the arrangement in space of the individual folded chains relative to one another held into clusters (haemoglobin, for example, has four polypeptide chains).

Generally, proteins are **fibrous** or **globular**. Fibrous look like fibers and globular – like a ball. Fibrous proteins as fibroin, keratin, collagen do not dissolve in water. Hormones, enzymes are globular proteins. They dissolve in water and are biologically active compounds (haemoglobin, albumin, insulin and many others).



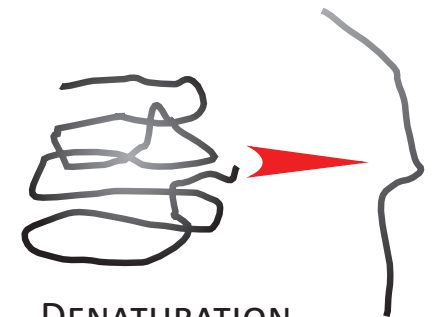
QUATERNARY STRUCTURE
(cluster of four polypeptide chains)

Proteins **hydrolyse** and **denaturate**. The final product of the proteins hydrolysis is a mixture of the α -amino acids whose residues build up the polypeptide chains of the molecules. The process is complex and undergoes under heating and in the presence of catalysts (acids or bases) or specific enzymes.



Polypeptide chains may contain other residues (of carbohydrates, phosphoric acid, nucleic acids, etc.). If so, the products of the hydrolysis are also all compounds whose residues build up molecules.

Hydrolysis affects the proteins primary structure. Under the action of some acids and bases, high temperature, irradiation, some solvents and others the secondary, tertiary and quaternary proteins structures can be damaged – the long polypeptide chains unfold and proteins lose their biological activity. The process is called **denaturation**. This is an irreversible process.



DENATURATION
OF A PROTEIN

The precipitation of proteins from their salt-containing (NaCl , MgCl_2 , NH_4Cl) solutions is known as **peptization**. Precipitated proteins dissolve if water is added.

CAN YOU ANSWER THESE QUESTIONS ?

1. What are organic compounds?
2. Both CaCO_3 and CH_4 have 1 C atom? Why is CH_4 an organic compound but CaCO_3 is an inorganic compound?
3. What are hydrocarbons?
4. What hydrocarbons are saturated and what – unsaturated?
5. What hydrocarbons are known as arenes?
6. What is functional group?
7. Alcohols, phenols, aldehydes, ketones and carboxylic acids are made of carbon C, hydrogen H and oxygen O but their properties are quite different. Why?
8. Both starch and cellulose are made of glucose residues but their biological role is completely different. Why?
9. What fats are „healthy“ fats?
10. What is the structure of proteins?

PROJECTS

1. CHEMICAL BONDING

Learn more about the different types of chemical bonds. Compare the properties of covalent, ionic and metallic compounds.

2. METALS AND NONMETALS

Choose one typical metal and one typical nonmetal. Compare their physical and chemical properties. Search information about some interesting their uses. How important are their properties for their uses in the industry or in household?

3. HYDROCARBONS AS FUELS

Learn more about the use of hydrocarbons as fuels. What are the major natural gas and crude oil fields in the world? Compare the properties of hydrocarbons composing natural gas and crude oil. Explain how their use affects the environment.

4. OXYGEN-CONTAINING ORGANIC COMPOUNDS

Compare two groups of oxygen-containing organic compounds on your choice. Discuss their properties and pay special attention to their uses.

5. CHONPS

This abbreviation summarises the chemical symbols of the most important for life chemical elements. Discuss that giving example of organic compounds maintaining life in plants, animals and humans.