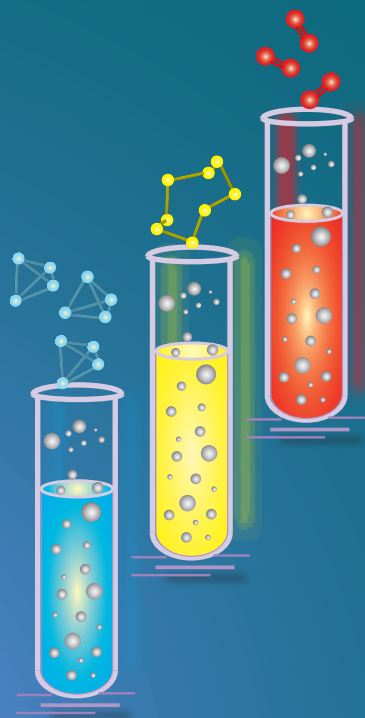


CLASSIFICATION OF CHEMICAL REACTIONS AND SUBSTANCES



- Metals
- Nonmetals
- Hydrocarbons
- Derivatives of hydrocarbons
- Carbohydrates, fats, proteins
- Oxidation-reduction reactions
- Single and double displacement reactions
- Homogeneous and heterogeneous reactions

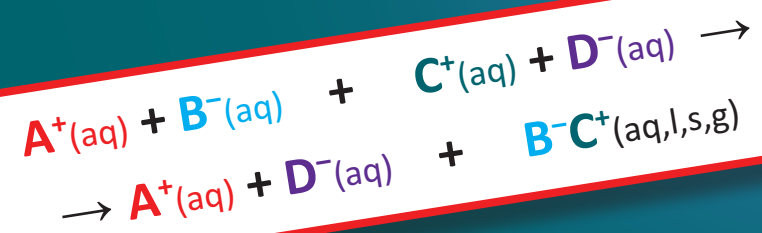
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25 Types of chemical reactions

KEY TOPICS

1. Why are chemical reactions grouped in classes?
2. What are the main types of chemical reactions?
3. What is the difference between a single displacement and a double displacement reaction?
4. What are homogeneous and heterogeneous reactions?



KEY WORDS

- Homogeneous reaction
- Heterogeneous reaction
- Exo- and endothermic reaction
- Reaction of synthesis
- Reaction of decomposition
- Single displacement reaction
- Double displacement reaction
- Oxidation-reduction reaction

WHAT ARE THE MAIN TYPES OF CHEMICAL REACTIONS?

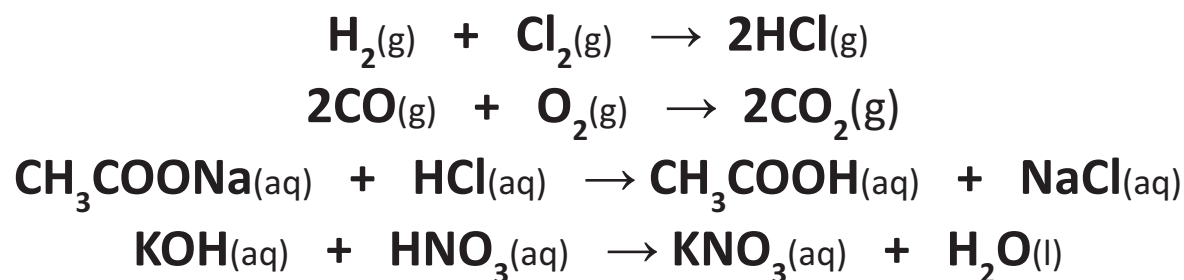
Today are known millions of inorganic and organic substances. They take part in millions of chemical reactions. On the basis of different criteria these millions of chemical interactions can be categorised into some main groups thus making their study and description easier. The scheme below gives an idea about the classification of chemical reactions according to some general criteria.

CRITERION	TYPES of REACTIONS
HEAT EFFECTS	EXOTHERMIC $\Delta H < 0$ (heat is lost) ENDOTHERMIC $\Delta H > 0$ (heat is gained)
PHYSICAL STATE OF REACTANTS	HOMOGENEOUS (reactions occur in a single phase*) HETEROGENEOUS (reaction components are part of two or more different phases)
REVERSIBILITY	REVERSIBLE (undergo in both directions and an equilibrium is established) IRREVERSIBLE (undergo only in the direction of the transformation of reactants into products)
ELECTRON TRANSFER	OXIDATION-REDUCTION REACTIONS (the oxidation numbers of reacting species change) EXCHANGE REACTIONS (the oxidation numbers of reacting species do not change)

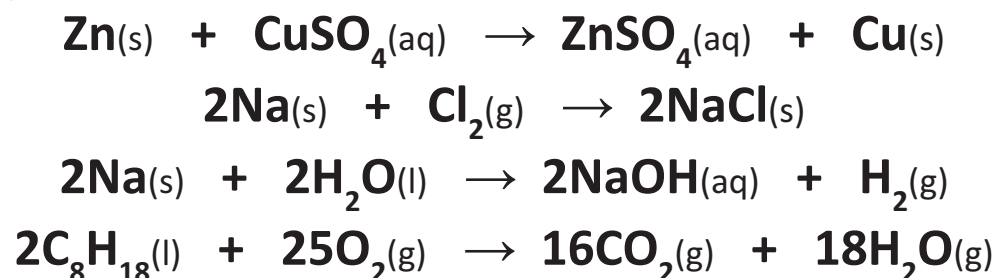
*A phase is matter that is uniform throughout its chemical composition and physical state.

You are already familiar with the exo- and endothermic reactions, the reversible and irreversible reactions, the oxidation-reduction reactions and the exchange reactions. Each of these reactions is homogeneous or heterogeneous reaction depending on the physical states of reactants.

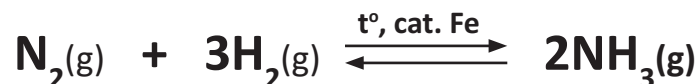
HOMOGENEOUS REACTIONS are chemical reactions occurring in a single phase (gaseous, liquid or solid). Most common are the reactions between gases and substances dissolved in liquids. For example:



HETEROGENEOUS REACTIONS are chemical reactions occurring in two or more phases (the reaction components are present in different phases – solid and liquid, solid and gaseous, liquid and gaseous, solid, liquid and gaseous). For instance:



Catalytic reactions undergoing on the surface of a catalyst are also heterogeneous reactions. A typical example is the catalytic reaction of hydrogen H_2 and nitrogen N_2 in the presence of iron Fe as a catalyst.



Another common criterion to classify chemical reactions is the nature of chemical changes occurring as a result of the reactions. Four main types of reactions are known – **synthesis**, **decomposition**, **single displacement** and **double displacement** reactions.

SYNTHESIS REACTIONS (also known as **combination reactions**). Two or more substances react to form a new compound. There is only one reaction product.



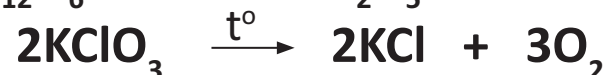
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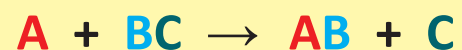
DECOMPOSITION REACTIONS. One single substance breaks down into two or more products.



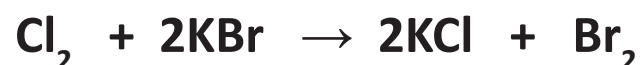
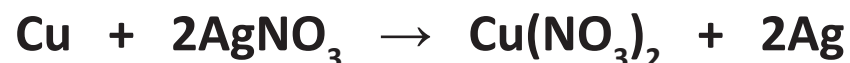
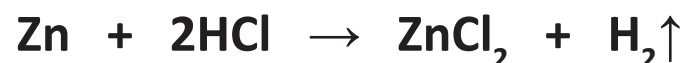
For example:



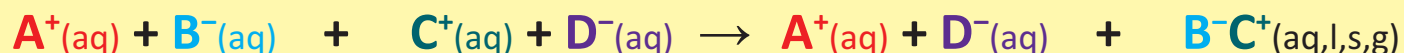
SINGLE DISPLACEMENT REACTIONS (also known as **single replacement reactions** or **substitution reactions**). One element in a compound is displaced (substituted) by another element. One of the reactants and one of the products are pure elements.



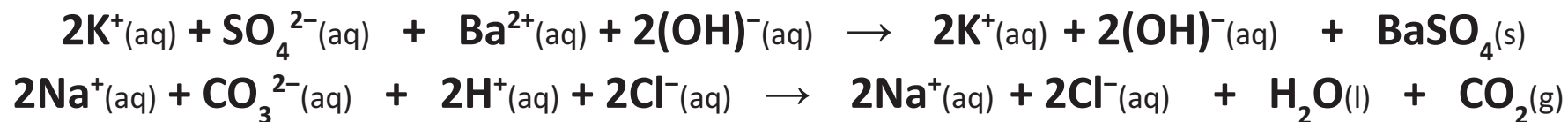
Typical are the reactions of active metals with water or acids and with salts of less active metals, also the displacement of halogen elements in their salts by more active halogen elements.



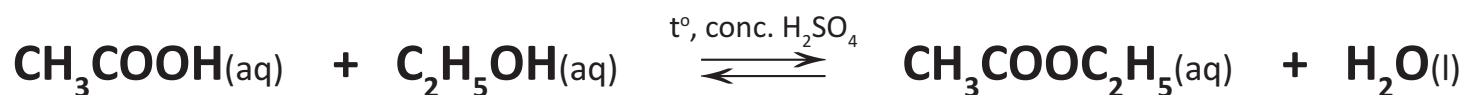
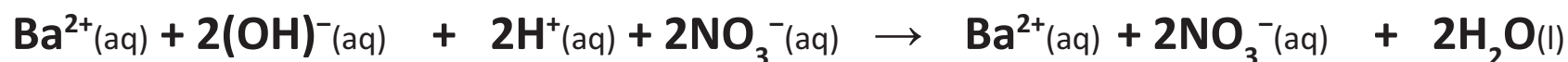
DOUBLE DISPLACEMENT REACTIONS (also known as **double replacement reactions** or **metathesis reactions** or **exchange reactions**). Generally, they occur in aqueous solutions of electrolytes – ions of two dissolved in water electrolytes (**AB** and **CD**) are exchanged forming a new compound (a weak electrolyte, a precipitate or a gas).



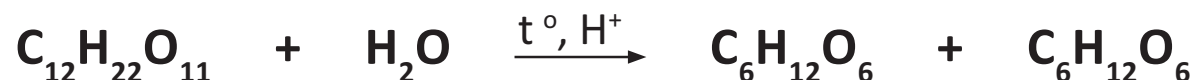
Dissolved electrolytes exchange their cations (positively charged ions) or their anions (negatively charged ions). For example:



The reactions of neutralisation and esterification are also typical reactions of double displacement as a weak electrolyte (water) is formed.



Other common types of reactions are the **combustion** and the **hydrolysis**. You are already familiar with these types of reactions. Hydrolysis is considered as a double decomposition reaction as both the water molecule and the reacting compound molecule break down to form two new compounds. For example saccharose $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ hydrolyses forming α -D-glucose and β -D-fructose.



Remember that a reaction can be categorised on the basis of two or more criteria. For example, the reaction of combustion of methane ($\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \longrightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$) is also an oxidation-reduction, homogeneous, exothermic, irreversible reaction.

CAN YOU ANSWER THESE QUESTIONS ?

1. How are chemical reactions categorised?
2. What are homogeneous and heterogeneous reactions?
3. What is the difference between a single and a double displacement reaction?
4. Why is the reaction of synthesis of NaCl from Na and Cl_2 also an oxidation-reduction reaction?
5. Is the precipitation of AgCl from an aqueous solution of AgNO_3 in a reaction with NaCl a single or a double displacement reaction?
6. Can you give an example of a single displacement heterogeneous reaction?
7. What catalytic reactions are homogeneous and what – heterogeneous reactions?
8. Can you give an example of a homogeneous reversible reaction?

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Classes of inorganic compounds

KEY TOPICS

1. What are the main classes of inorganic compounds?
2. What reactions are typical for oxides?
3. What reactions are typical for bases?
4. What reactions are typical for acids?
5. What reactions are typical for salts?

KEY WORDS

- Elements
- Metals
- Nonmetals
- Chemical compounds
- Acidic oxides
- Basic oxide
- Amphoteric oxide
- Neutral oxides
- Base (Basic hydroxide)
- Acid (Acidic hydroxide)
- Polyprotic acid
- Amphoteric hydroxide
- Salt



WHAT ARE THE MAIN CLASSES OF INORGANIC SUBSTANCES?

All substances that do not contain carbon atoms are inorganic substances. Carbon itself, its oxides (CO and CO_2), carbonic acid (H_2CO_3) and its salts and a few other carbon-containing substances are considered as inorganic substances too as their properties are similar to the properties of the inorganic substances.

Inorganic substances are made up of identical atoms or of the atoms of two or more chemical elements. Substances made up of identical atoms are called **ELEMENTS***. Substances built up of atoms of two or more different chemical elements are called **CHEMICAL COMPOUNDS**. These are the two main classes of inorganic substances.

CLASSES OF ELEMENTS

Substances made up of atoms of a *metallic element* are **metals**. Substances made up of atoms of a *nonmetallic element* are **nonmetals**.

Metals are much more than nonmetals but their properties are similar. Alkali (Li, Na, K, Rb, Cs) and alkaline-earth metals (Ca, Sr, Ba) and Mg are typical metals. Aluminum Al is also a metal. The elements of the secondary groups (from 3rd (IIIB) to 12th (IIB)), for example, Cr, Mn, Fe, Ni, Zn, Cu, etc., are also metals. They are known as **transition metals**.

Nonmetals are much less than metals but their properties are various. Typical nonmetals are the elements of 17 (VIIA) groups – F_2 , Cl_2 , Br_2 , I_2 , but also oxygen O_2 , sulfur S, nitrogen N_2 , phosphorus P, carbon C. Hydrogen is also considered as a nonmetal.

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

ELEMENTS

METALS

NONMETALS

In the tables below are compared the physical and chemical properties of typical metals and typical nonmetals.

PHYSICAL PROPERTIES	METALS	NONMETALS
Physical state	Solid (Hg is liquid)	Gaseous or solid (Br ₂ is liquid)
Colour and lustre	Silvery-white with metallic lustre	Coloured or colourless
Odour	—	With specific odour or odourless
Structure	Crystalline (metallic lattice)	Crystalline (atomic or molecular) or amorphous; diatomic gaseous molecules
Thermal and electrical conductivity	Conduct heat and electricity	Insulators (graphite conducts electricity)
Density	Generally, high	Generally, low
Hardness	Generally, soft	Diamond is very hard, graphite is soft.
Plasticity	Ductile and malleable	Some are brittle
Boiling and melting point	Generally, high	Generally, low

CHEMICAL PROPERTIES	METALS	NONMETALS
Reaction with oxygen O ₂	Form oxides	Form oxides. Some do not react directly.
Reaction with hydrogen H ₂	Form hydrides	Form hydrogen compounds
Reaction with metals	---	Form salts
Reaction with nonmetals	Form salts	Some nonmetals react with other nonmetals.
Reaction with water	Form bases and H ₂ is liberated	Not a typical reaction
Reaction with acids	Form salts and H ₂ is liberated	---
Reaction with bases	---	Not a typical reaction
Reaction with salts	Active metals displace less active metals from their salts.	Some nonmetals can displace other nonmetals from their salts.

The properties of sodium Na (a typical metal) and chlorine Cl₂ (a typical nonmetal) are compared in the table below.

PHYSICAL PROPERTIES	SODIUM Na	CHLORINE Cl ₂
Physical state	Solid	Gaseous
Colour and lustre	Silvery-white with metallic lustre	Yellow-greenish
Odour	—	Sharp, pungent
Structure	Crystalline (metallic lattice)	Diatomic gaseous molecules Cl ₂
Thermal and electrical conductivity	Conduct heat and electricity	Insulators
Density	971 kg/m ³	3,2 g/m ³ (at 0 °C and 10 ⁵ Pa)
Hardness	Soft, can be cut with a knife.	---
Plasticity	Ductile and malleable	---
Boiling and melting point	883 °C; 98 °C	-101 °C; -35 °C

CHEMICAL PROPERTIES	SODIUM Na	CHLORINE Cl ₂
Reaction with oxygen O ₂	$4\text{Na} + \text{O}_2 \rightarrow 2\text{Na}_2\text{O}; 2\text{Na} + \text{O}_2 \rightarrow \text{Na}_2\text{O}_2$	Does not react directly.
Reaction with hydrogen H ₂	$2\text{Na} + \text{H}_2 \rightarrow 2\text{NaH}$	$\text{H}_2 + \text{Cl}_2 \rightarrow 2\text{HCl}$
Reaction with metals	---	$2\text{K} + \text{Cl}_2 \rightarrow 2\text{KCl}; \text{Ca} + \text{Cl}_2 \rightarrow \text{CaCl}_2$
Reaction with nonmetals	$2\text{Na} + \text{Cl}_2 \rightarrow 2\text{NaCl}; 2\text{Na} + \text{S} \rightarrow \text{Na}_2\text{S}$	$2\text{P} + 3\text{Cl}_2 \rightarrow 2\text{PCl}_3$
Reaction with water	$2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2\uparrow$	$\text{Cl}_2 + \text{H}_2\text{O} \rightarrow \text{HCl} + \text{HClO}$
Reaction with acids	$2\text{Na} + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2\uparrow$	---
Reaction with bases	---	$\text{Cl}_2 + 2\text{NaOH} \rightarrow \text{NaCl} + \text{NaClO} + \text{H}_2\text{O}$
Reaction with salts	Na reacts with water. The displacement reaction of less active metals does not undergo.	$\text{Cl}_2 + 2\text{KBr} \rightarrow 2\text{KCl} + \text{Br}_2$

CLASSES OF INORGANIC COMPOUNDS

On the basis of similarities in their composition and chemical properties inorganic chemical compounds are grouped into four main classes – **oxides**, **bases**, **acids** and **salts**.

The **hydrides** (compounds of metals with hydrogen) and the **hydrogen compounds** of nonmetals (HCl, HBr, HI, H₂S, etc.) are two other classes of inorganic substances.

The bases and the oxygen-containing acids form a common class of inorganic substances – the **hydroxides**. They have one or more hydroxide group OH⁻. They are considered as obtained in a reaction of an oxide with water.



OXIDES

Oxides are the most abundant chemical compounds in the Earth's crust (about 50 %). Almost all chemical elements form oxides. Metals from the main groups of the periodic table form only one oxide (e.g. disodium oxide Na₂O, calcium oxide CaO, dialuminum trioxide Al₂O₃, etc.). Generally, nonmetals form two or more oxides – CO and CO₂, N₂O, NO, N₂O₃, NO₂ and N₂O₅, SO₂ and SO₃, Cl₂O, ClO, Cl₂O₃, ClO₂, ClO₃, Cl₂O₇, etc.

CHEMICAL COMPOUNDS

OXIDES

BASES

ACIDS

SALTS

Physical properties. The oxides of metals are ionic crystalline substances. Some oxides of nonmetals under standard conditions are gases (CO , CO_2 , N_2O , SO_2 , Cl_2O), others are liquids (Cl_2O_7) or solids (SO_3 , I_2O_5 , SiO_2 , P_2O_5). Several oxides are coloured (e.g. nitrogen dioxide NO_2 is reddish-brown). Some have specific odour (e.g. SO_2 has a specific pungent odour).

Chemical properties. Depending on their properties oxides are classified as acidic, basic or amphoteric. Typical metals form basic oxides and typical nonmetals form acidic oxides. Some metals (aluminum Al , zinc Zn) form amphoteric oxides. The sets of chemical reactions determining the character of the oxides are presented below.

OXIDES

Na_2O , CaO , CuO

BASIC

SO_3 , Cl_2O_7 , P_2O_5

ACIDIC

Al_2O_3 , ZnO

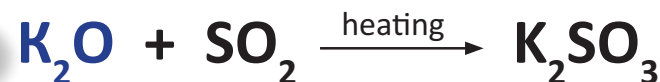
AMPHOTERIC

BASIC OXIDES

+ $\text{H}_2\text{O} \rightarrow \text{BASE}^*$



+ ACIDIC OXIDE $\rightarrow$ SALT



+ ACID $\rightarrow$ SALT + H_2O



* Only soluble basic oxides react with water –

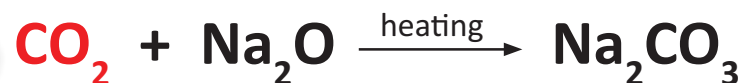
Li_2O , Na_2O , K_2O , Rb_2O , Cs_2O , CaO , BaO , SrO

ACIDIC OXIDES

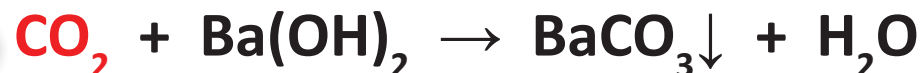
+ WATER → ACIDS



+ BASIC OXIDE → SALT



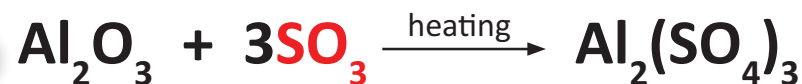
+ BASE → SALT + H₂O



AMPHOTERIC OXIDES

Amphoteric oxides are insoluble in water and do not react with it.

+ ACIDIC OXIDE → SALT



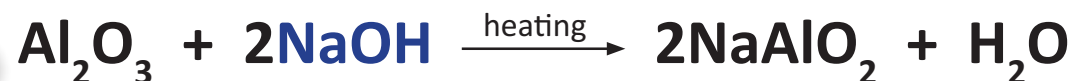
+ BASIC OXIDE → SALT



+ ACID → SALT + H₂O



+ BASE → SALT + H₂O



Some oxides do not react either with bases or with acids. They do not react with water too. They are known as **neutral oxides**. CO, N₂O, NO are neutral oxides.

BASES

BASES (or **basic hydroxides**) are chemical compounds containing one or more hydroxide ions OH^- bonded to ions of metallic elements. 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 usually used to indicate the number of hydroxy groups bonded to one metallic atom – $\text{Ca}(\text{OH})_2$ calcium dihydroxide, $\text{Al}(\text{OH})_3$ aluminum trihydroxide. But often, for simplicity, they are also called „bases“. The soluble in water bases dissociate into positive metal ions and negative hydroxide ions OH^- when dissolved in water.



For all aqueous solutions of bases $\text{pH} > 7$. Litmus turns blue and phenolphthalein is pink-red.

Physical properties. Bases are crystalline substances. Many of them are white or colourless. Some hydroxides of transition metals have a characteristic colour – copper dihydroxide $\text{Cu}(\text{OH})_2$ is blue, iron trihydroxide $\text{Fe}(\text{OH})_3$ is brown, nickel dihydroxide $\text{Ni}(\text{OH})_2$ is green.

The bases of the alkali and the alkaline earth-metals are hygroscopic and soluble in water. An exception is $\text{Ca}(\text{OH})_2$ which is slightly soluble. Most of the hydroxides of the other metals are insoluble in water.

The soluble in water bases are „slippery“. They burn up the skin and the cloths. 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

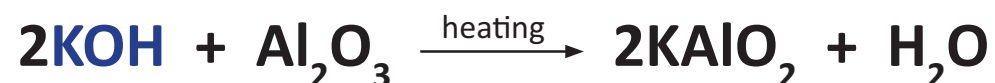
Chemical properties. Bases are reactive compounds. They react with acidic and amphoteric oxides, acids and amphoteric hydroxides.

BASES

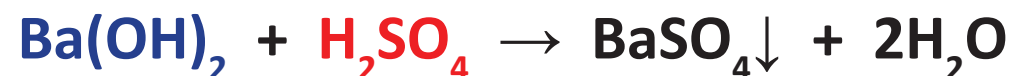
+ ACIDIC OXIDE $\rightarrow$ SALT + H₂O



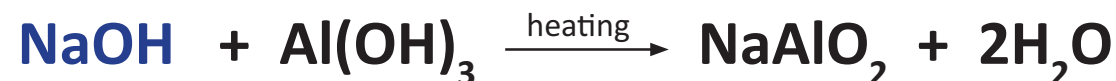
+ AMPHOTERIC OXIDE $\rightarrow$ SALT + H₂O



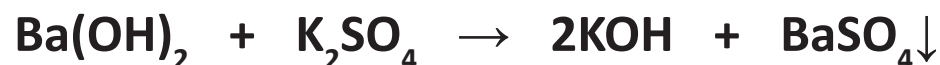
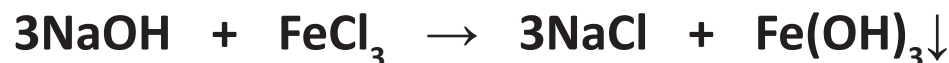
+ ACID $\rightarrow$ SALT + H₂O



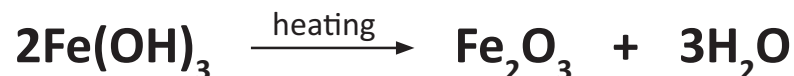
+ AMPHOTERIC HYDROXIDE $\rightarrow$ SALT + H₂O



Bases react also with soluble salts when the reaction product is an insoluble hydroxide or salt. For example:



Insoluble basic hydroxides decompose under heating releasing water.



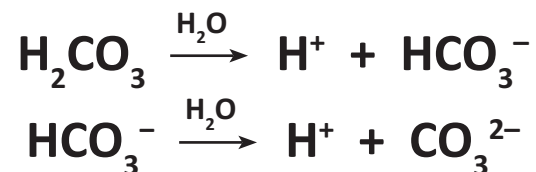
ACIDS

ACIDS are chemical compounds that, if soluble, dissociate into positive hydrogen ions H^+ (or hydronium ions H_3O^+) and negative acidic ions when dissolved in water. Binary acids (aqueous solutions of hydrogen halides, H_2S , etc.) liberate Cl^- , Br^- , S^{2-} anions, etc. The acidic ions of oxygen-containing acids (e.g. H_2SO_4 , HNO_3 , etc.) are complex anions as SO_4^{2-} , NO_3^- , etc.



Oxygen-containing acids are also known as **acidic hydroxides** as they contain $-\text{OH}$ groups in their molecules.

Acids with more than 1 H atom in their molecules are called **polyprotic acids** or **polyacids**. They dissociate liberating more than one H^+ cations (as the H^+ ion is in fact a proton, these acids are called polyprotic acids). Carbonic acid H_2CO_3 ionises in two steps:



Carbonic acid H_2CO_3 is a diprotic acid. Phosphoric acid H_3PO_4 is a triprotic acid. Hydrochloric acid HCl is a **monoprotic acid**.

For all aqueous solutions of acids $\text{pH} < 7$. Litmus turns red and phenolphthalein is colourless.

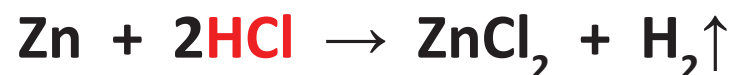
Concentrated strong acids (sulfuric H_2SO_4 , nitric HNO_3 , perchloric HClO_4) are extremely dangerous! They burn up the skin, the cloths, the plastics. Safety precautions (goggles, protective gloves and an apron) are obligatory when working with such substances.

Physical properties. Most of the acids are colourless liquids (sulfuric H_2SO_4 , nitric HNO_3 , hydrosulfuric H_2S , hydrochloric HCl , etc.). Some acids are solid substances. For example, boric acid H_3BO_3 is a white crystalline substance.

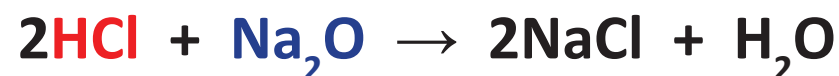
Chemical properties. Acids are reactive compounds. They react with active metals, basic and amphoteric oxides, bases and amphoteric hydroxides.

ACIDS

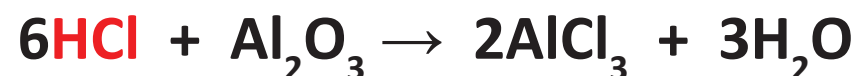
+ ACTIVE METALS $\rightarrow$ SALT + $\text{H}_2\uparrow$



+ BASIC OXIDE $\rightarrow$ SALT + H_2O



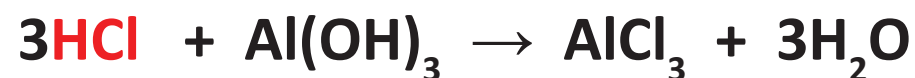
+ AMPHOTERIC
OXIDE $\rightarrow$ SALT + H_2O



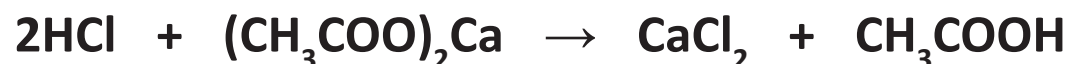
+ BASE $\rightarrow$ SALT + H_2O



+ AMPHOTERIC
HYDROXIDE $\rightarrow$ SALT + H_2O



Acids react also with soluble salts when the reaction product is an insoluble salt, an acid with a low degree of dissociation (a weak electrolyte) or a gas. For example:



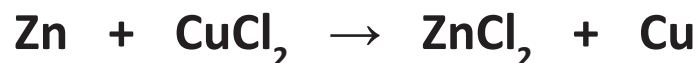
SALTS

SALTS are chemical compounds that can be considered as products of the neutralisation of acids and bases. Salts of binary acids are built up of positive metal ions (Na^+ , K^+ , Zn^{2+} , Al^{3+} etc.) and negative ions of nonmetals (Cl^- , Br^- , S^{2-} , etc.). For example, NaCl , KBr , ZnS , AlCl_3 . Salts of oxy-acids are made up of positive metal ions and negative acidic ions (SO_4^{2-} , NO_3^- , SO_3^{2-}). For example, Na_2SO_4 , KNO_3 , Na_2SO_3 .

Physical properties. Most of the salts are high-melting crystalline substances with various colours. The salts of the alkali metals are soluble in water. Salts of the nitric acid HNO_3 (the nitrates) are soluble in water too. Some salts, as CaSO_4 , Ag_2SO_4 , PbCl_2 (lead dichloride) are slightly soluble in water. Other salts as AgCl , BaSO_4 , CuS , are practically insoluble in water.

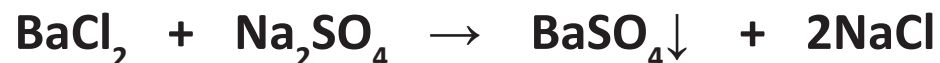
Chemical properties. Besides the already discussed reactions of salts with acids and bases some salts also react with metals, other salts and thermally decompose.

– **Interaction with metals.** Soluble salts react with metals that are more active than the metal of the salt. For example:



Alkali and the alkaline-earth metals do not displace less active metals in the aqueous solutions of their salts. They react vigorously with water and hydrogen gas is evolved!

– **Interaction with salts.** A chemical reaction between soluble salts occurs when insoluble salts are produced. For example:



– **Thermal decomposition.** Some salts of oxygen-containing acids (nitrates, sulfates, carbonates) decompose under heating. For instance:



The burning of lime is one of the oldest chemical technological process.

CAN YOU ANSWER THESE QUESTIONS ?

1. What are the main classes of inorganic compounds?

2. Which of the elements below are metals?

Br_2 Hg N_2 C Ba H_2 Na O_2 Mg Fe Zn

3. What set of chemical reactions determines the acidic character of SO_3 ?

4. What set of chemical reactions determines the basic character of CaO?

5. A chemical compound reacts with acidic oxides and acids? Is this a base or an acid?

6. A chemical compound reacts with Na, K_2O and $\text{Ca}(\text{OH})_2$? Is this HCl or $\text{Ba}(\text{OH})_2$?

7. A neutralisation reaction yields water H_2O and a?

8. Does NaCl react with AgNO_3 and H_2SO_4 ? Why?

27

Classes of organic compounds

KEY TOPICS

1. What are the main classes of hydrocarbons?
2. What are the main classes of hydrocarbon derivatives?
3. What are the main classes of organic compounds of biological importance?

KEY WORDS

- Aliphatic hydrocarbons
- Aromatic hydrocarbons
- Alcohols and phenols
- Aldehydes and ketones
- Carboxylic acids
- Amino acids
- Fats and oils
- Carbohydrates
- Proteins

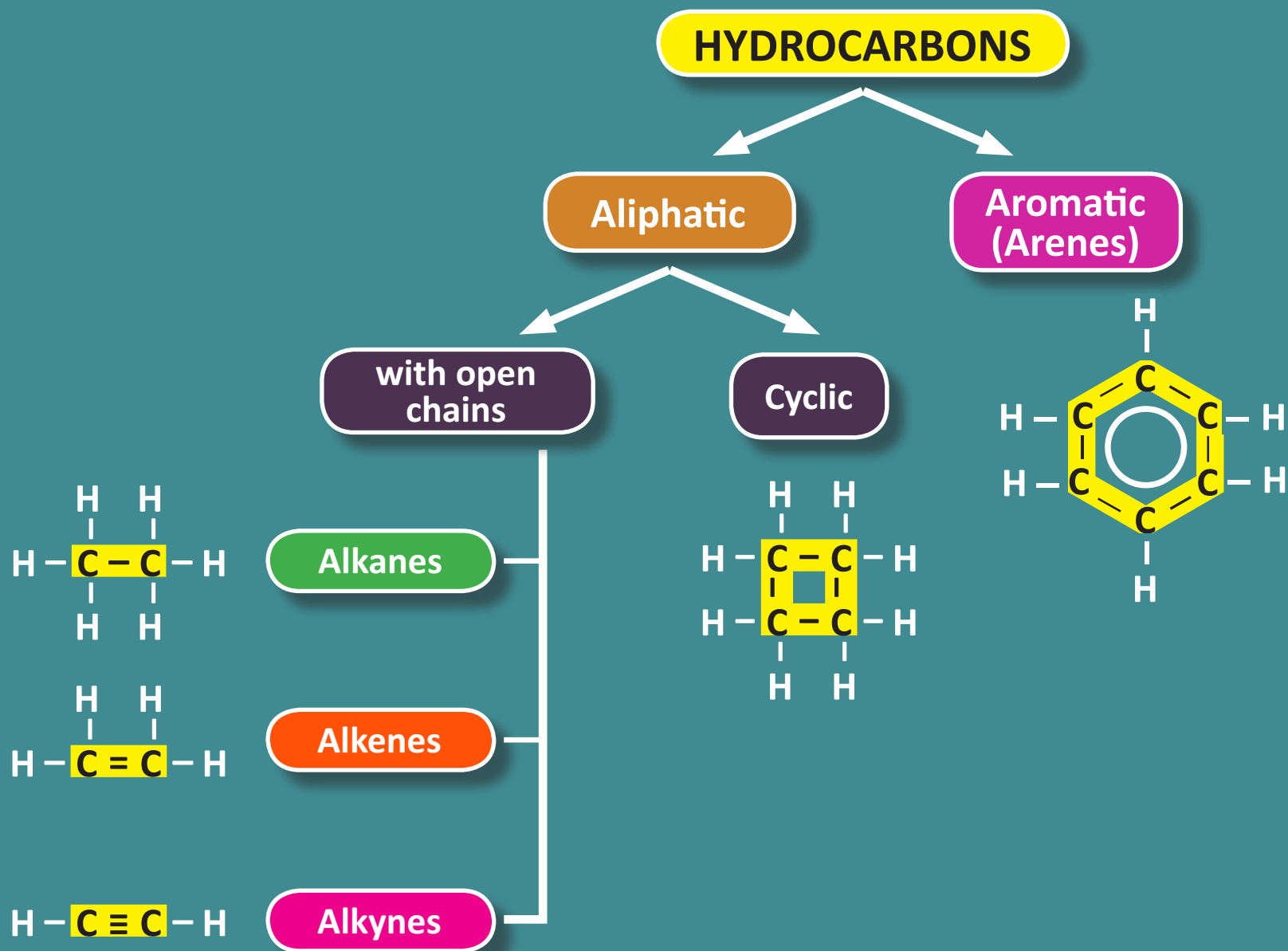
WHAT ARE THE MAIN CLASSES OF ORGANIC COMPOUNDS?

Today are known millions of organic compounds – naturally occurring and man-made (www.cas.org provides information about all known substances). Depending on their composition and structure organic compounds form several classes of chemical compounds. Hydrocarbons are the simplest organic compounds. Their derivatives form other classes of organic compounds depending on the functional groups in their molecules.

HYDROCARBONS

Depending on the structure of their carbon skeleton hydrocarbons are classified as **aliphatic** and **aromatic**. The carbon chains of the aliphatic hydrocarbons are open (straight or branched) or closed (cyclic). All aromatic hydrocarbons (**arenes**) have in their molecules an aromatic ring of 6 carbon atoms.

Aliphatic hydrocarbons are **saturated** (contain the maximum number of hydrogen atoms) or **unsaturated** (contain adjacent C atoms linked by multiple (double or triple) bonds). **Alkanes** are saturated hydrocarbons. **Alkenes** and **alkynes** are classes of unsaturated hydrocarbons. They have double (alkenes) or triple (alkynes) carbon-carbon bonds in their molecules. The scheme on the next page summarises the main classes of hydrocarbons.

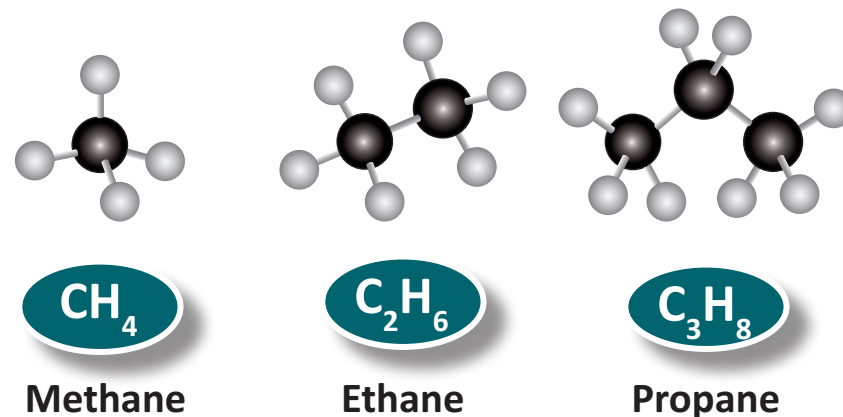
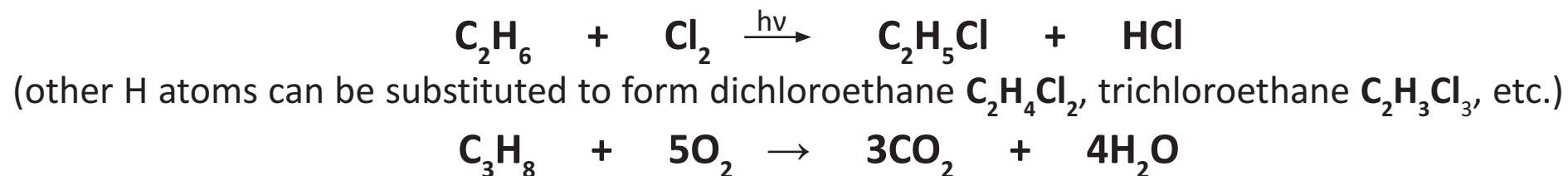


ALKANES

ALKANES, also known as *paraffins*, are the simplest hydrocarbons. All carbon atoms in their molecules are single bonded. The simplest alkane is methane CH_4 . The next homologues are ethane C_2H_6 , propane C_3H_8 and butane C_4H_{10} . The general formula of this class of hydrocarbons is $\text{C}_n\text{H}_{2n+2}$. Their properties depend on the number of C atoms in their molecules and on the structure of the carbon chains. Alkanes with four and more carbon atoms have chain isomers.

Physical properties. At standard conditions the first four homologues of alkanes are gases. They are colourless and odourless gases. The next homologues are liquids with a specific odour (of petrol). Alkanes with straight chains of 14 and more C atoms are solids at standard conditions. All alkanes are insoluble in water.

Chemical properties. Alkanes are not very reactive compounds. Typical reactions of alkanes are their **halogenation** (a substitution reaction) and their **combustion**. For example:

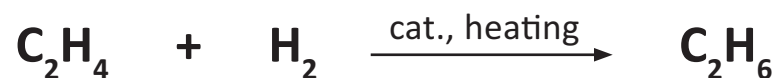


ALKENES

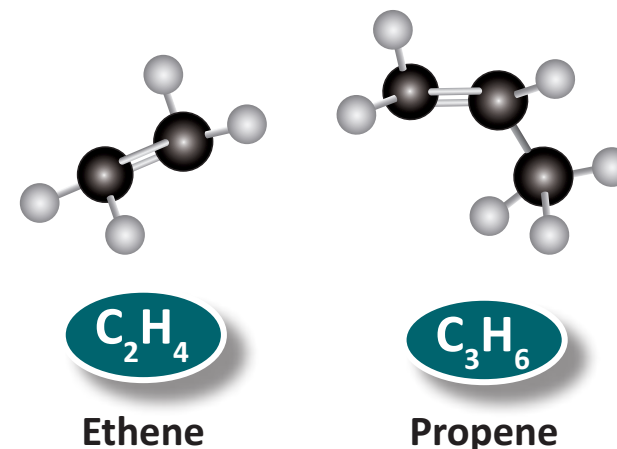
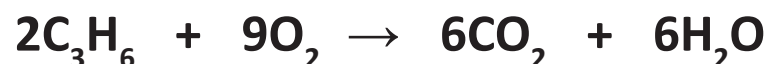
ALKENES, also known as *olefins* are unsaturated hydrocarbons with double bonded carbon atoms $\text{>C}=\text{C}<$. Their general formula is C_nH_{2n} . The simplest alkene is ethene C_2H_4 . The second homologue is propene C_3H_6 , etc. Alkenes with four and more carbon atoms have chain and position isomers.

Physical properties. At standard conditions the first three homologues are gases. The next are liquids and the higher alkenes are solids. Alkenes are insoluble in water.

Chemical properties. Alkenes are more reactive than alkanes. Typical reactions of alkenes are the addition reactions (**hydrogenation**, **halogenation**, **addition of hydrogen halides**, **hydration**), also their **polymerization** and **combustion**. For example:



The discoloration of bromine water is a test reaction for unsaturated hydrocarbons.

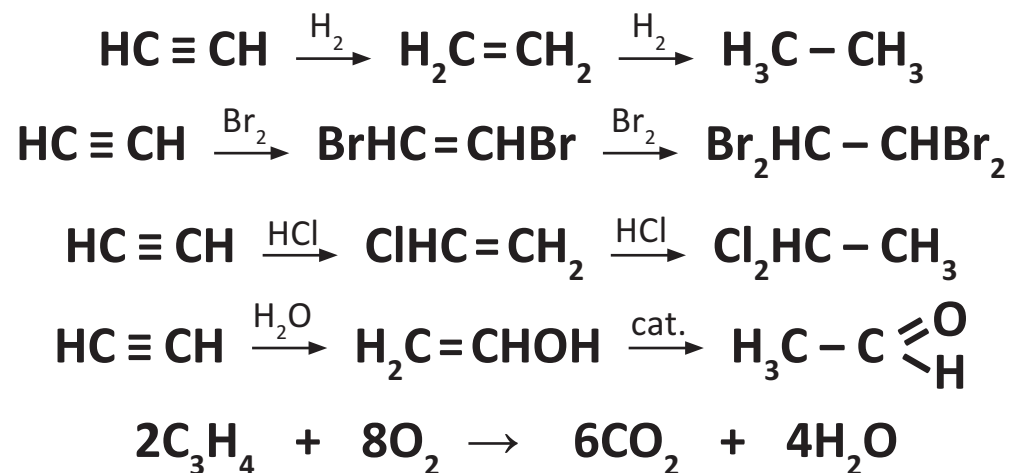
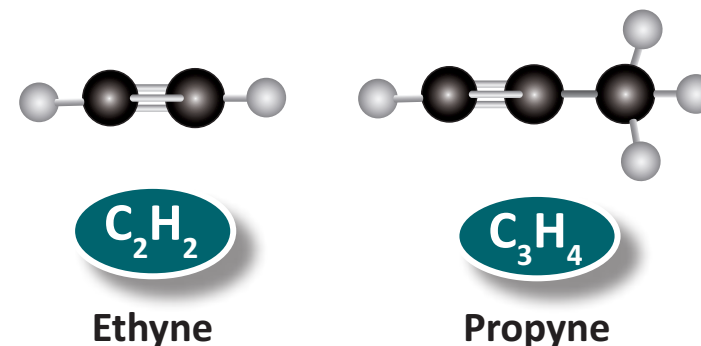


ALKYNES

ALKYNES are unsaturated hydrocarbons with triple bonded carbon atoms – $\text{C} \equiv \text{C}$ –. Their general formula is $\text{C}_n\text{H}_{2n-2}$. The simplest alkyne is ethyne C_2H_2 . The second homologue is propyne C_3H_4 , etc. Alkynes with four and more carbon atoms have position isomers. Alkynes with five and more carbon atoms have chain isomers too.

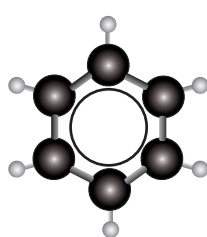
Physical properties. At standard conditions the first three homologues are colourless gases. The next are liquids and the higher alkynes are solids. Alkynes are odourless and insoluble in water. Ethyne has a specific odour.

Chemical properties. Alkynes are reactive compounds. Typical of alkynes are the addition reactions (**hydrogenation**, **halogenation**, **addition of hydrogen halides**, **hydration**) and combustion.

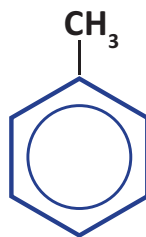


ARENES

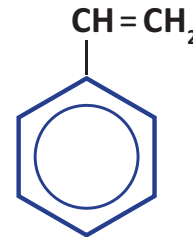
ARENES, also known as aromatic hydrocarbons, have an aromatic ring of 6 carbon atoms in their molecules. The simplest arene is benzene C_6H_6 . The other arenes are its derivatives – in their molecules one or more H atoms have been substituted by hydrocarbons groups. Benzene derivatives have position isomers.



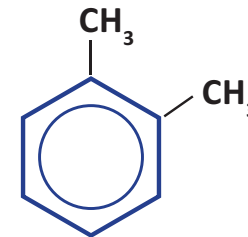
Benzene



Methylbenzene
(toluene)



Ethenylbenzene
(styrene)

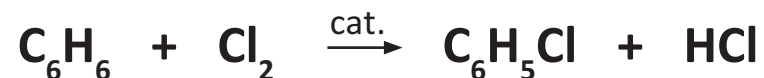


1,2-dimethylbenzene
(o-xylene)

Physical properties. At standard conditions benzene is a volatile liquid. It is insoluble in water. Benzene is a flammable liquid with a specific odour.

Benzene is a toxic compound. It is considered as a class A carcinogen. It can be inhaled or absorbed through the skin. It may have a narcotic effect. Benzene is a serious pollutant of soils and water.

Chemical properties. The substitution of one or more H atoms by other atoms or atomic groups are the most common reactions of benzene. These reactions are essential for its aromatic character. For example:

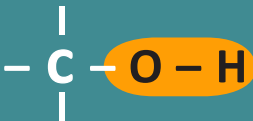
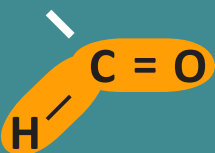
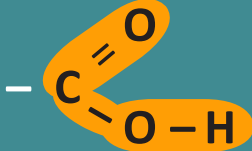
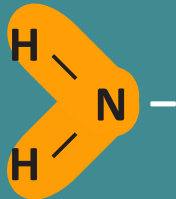


Under special conditions benzene takes part also in addition reactions.



DERIVATIVES OF HYDROCARBONS

The simplest hydrocarbon derivatives are their halogen derivatives (e.g. chloromethane CH_3Cl , tetrachloromethane CCl_4 , bromoethene $\text{C}_2\text{H}_3\text{Br}$, chlorobenzene $\text{C}_6\text{H}_5\text{Cl}$ etc.). The other hydrocarbon derivatives have one or more functional groups in their molecules. The major classes of hydrocarbon derivatives correspond to the major types of functional groups.

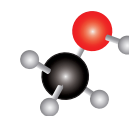
FUNCTIONAL GROUP					
	HYDROXY	ALDEHYDE	KETONE	CARBOXYL	AMINO
HYDROCARBON DERIVATIVES	ALCOHOLS	ALDEHYDES	KETONES	CARBOXYLIC ACIDS	AMINES

HYDROXY DERIVATIVES

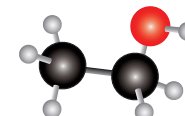
HYDROXY DERIVATIVES of hydrocarbons contain one or more **hydroxy groups** -OH . **ALCOHOLS** are hydroxy derivatives of aliphatic hydrocarbons. **PHENOLS** are hydroxy derivatives of aromatic hydrocarbons in whose molecules the -OH group is bonded directly to the aromatic ring. Hydroxy derivatives are classified as **monohydric** (with one -OH group) and **polyhydric** (with two or more -OH groups).

Physical properties. Methanol CH_3OH and ethanol $\text{C}_2\text{H}_5\text{OH}$ are colourless, volatile, flammable liquids. Ethanol has a pungent taste and a characteristic vinous odour, while methanol has a distinctive odour. Methanol, ethanol, ethane-1,2-diol (glycol) and propane-1,2,3-triol (glycerine) all are miscible with water in any proportions. Ethane-1,2-diol lowers significantly the freezing point of water. At standard conditions it is a colourless liquid with a sweet taste (but it is poisonous). Propane-1,2,3-triol is a viscous colourless liquid with a sweet taste too. Both polyhydric alcohols are heavier than water (unlike methanol and ethanol which are lighter).

Phenol (benzenol, hydroxybenzene or carbolic acid) $\text{C}_6\text{H}_5\text{OH}$ is a colourless crystalline solid with a specific odour. It is a weak acid. Its aqueous solution (carbolic acid) is an antiseptic.

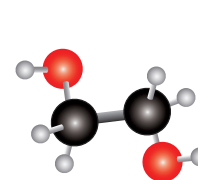


$\text{H}_3\text{C}-\text{OH}$
 CH_3OH
Methanol

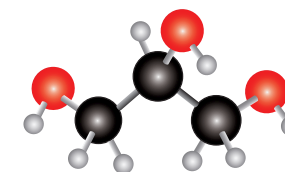


$\text{H}_3\text{C}-\text{H}_2\text{C}-\text{OH}$
 $\text{C}_2\text{H}_5\text{OH}$
Ethanol

MONOHYDRIC ALCOHOLS

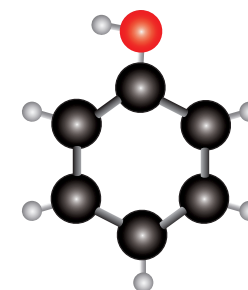


$\text{HO}-\text{CH}_2-\text{CH}_2-\text{OH}$
 $\text{C}_2\text{H}_4(\text{OH})_2$
Ethane-1,2-diol



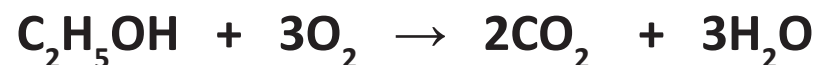
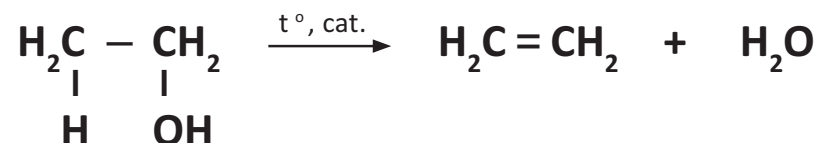
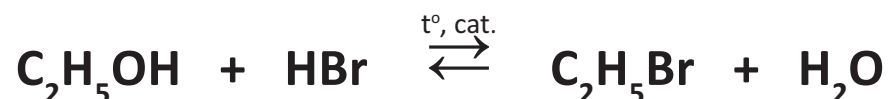
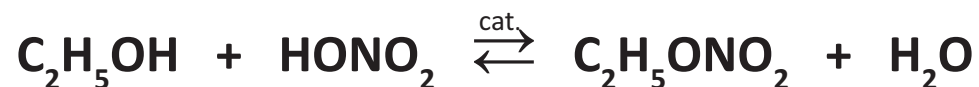
$\text{H}_2\text{C}-\text{CH}_2-\text{CH}_2$
 $\text{HO}-\text{OH}-\text{OH}$
 $\text{C}_3\text{H}_6(\text{OH})_3$
Propane-1,2,3-triol

POLYHYDRIC ALCOHOLS



OH
 $\text{H}-\text{C}_6\text{H}_4-\text{H}$
 $\text{C}_6\text{H}_5\text{OH}$
PHENOL
(HYDROXYBENZENE)

Chemical properties. Alcohols are reactive compounds. Typical reactions of alcohols are the interactions with **active metals**, **oxy-acids**, **hydrogen halides**, their **dehydration**, **esterification** with carboxylic acids (see p.36) and **combustion**. For example:



Ethanol and methanol are renewable biofuels.

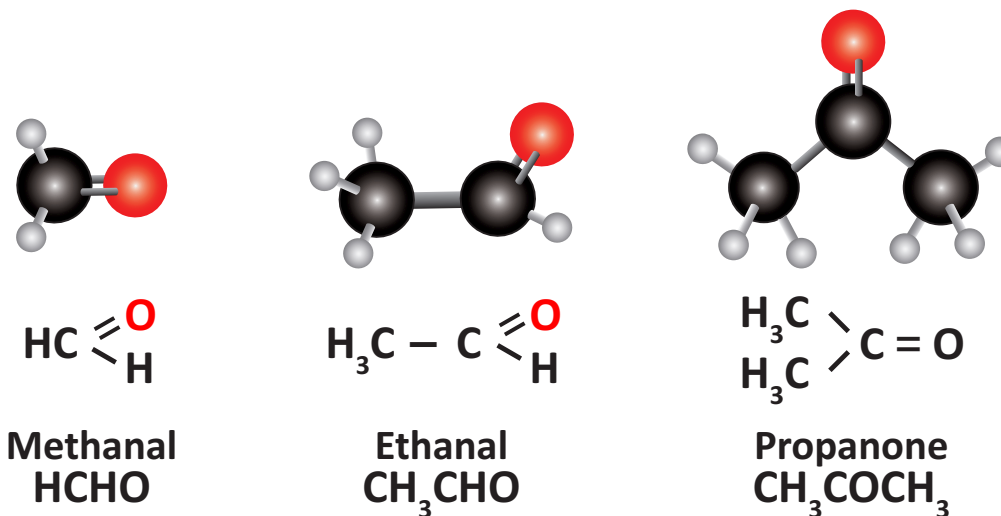
ALDEHYDES and KETONES

The **carbonyl group** is a diatomic group formed by double bonded carbon and oxygen atoms >C=O . **Carbonyl derivatives** of hydrocarbons (aldehydes and ketones) always have at least one carbonyl group in their molecules. **ALDEHYDES** contain at least one **aldehyde group** O=C<H . It is always at the end of the carbon chain. In condensed structural formulae it is expressed as **-CHO**.

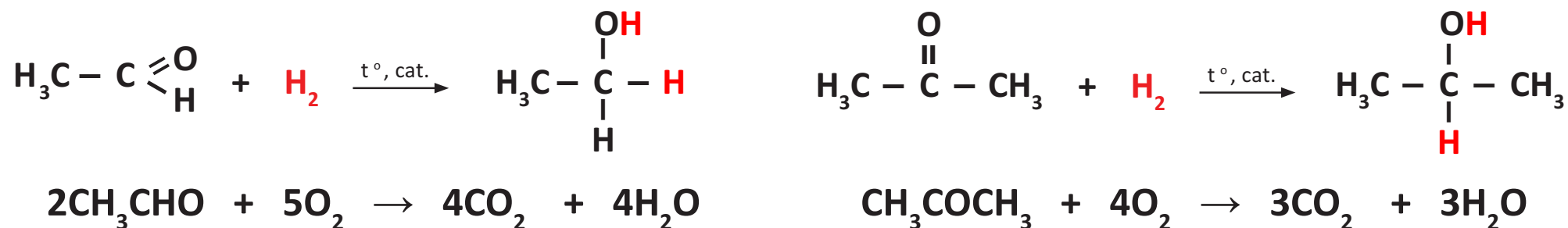
The simplest aldehydes are methanal **HCHO** and ethanal **CH₃CHO**. **KETONES** have carbonyl groups inside the carbon chains. The simplest ketone is propanone **CH₃COCH₃**.

Physical properties. At standard conditions methanal HCHO is a colourless gas, while ethanal CH₃CHO is a colourless liquid. Both methanal and ethanal have a specific sharp, irritating odour. They are soluble in water. The 37 % aqueous solution of methanal is known as formalin.

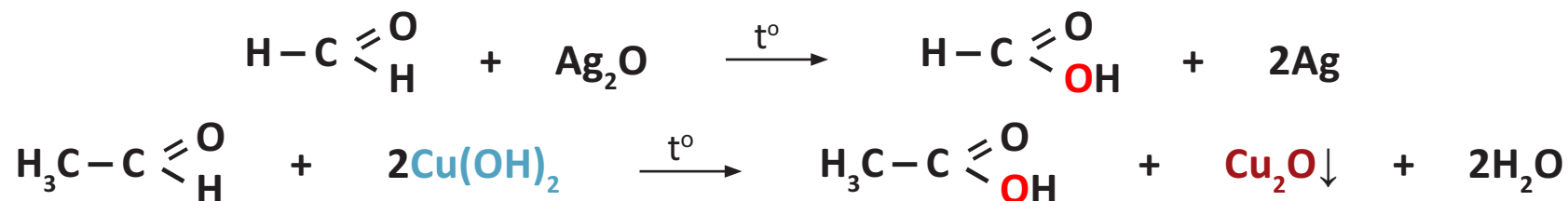
Propanone is a colourless, volatile, flammable liquid with a specific sharp odour. Propanone is a very good solvent of many organic compounds.



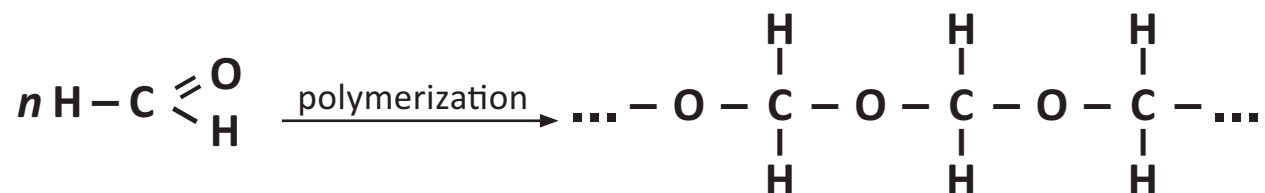
Chemical properties. Typical reactions of both aldehydes and ketones are their **hydrogenation** and **combustion**. For example:



Well known reactions of aldehydes are also their **oxidation by disilver oxide Ag_2O** (silver mirror test) or **copper dihydroxide $\text{Cu}(\text{OH})_2$** , as well as the **polymerization of methanal**. For example:



Both reactions are test reactions for aldehydes. Aldehydes are oxidized even by oxygen in the air.



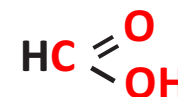
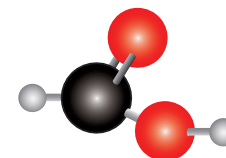
Polyformaldehyde plastics are commonly known as POM (polyoxymethylene) plastics.

CARBOXYLIC ACIDS

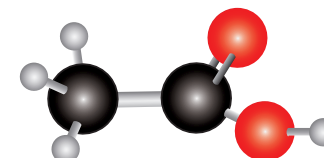
CARBOXYLIC ACIDS have one or more carboxyl groups $-\text{C}(=\text{O})\text{OH}$ ($-\text{COOH}$). The general formula of the monovalent (with one carboxyl group) saturated carboxylic acids is $\text{C}_n\text{H}_{2n+1}\text{COOH}$. Methanoic acid HCOOH and ethanoic acid CH_3COOH are the simplest carboxylic acids with open chains. Benzoic acid $\text{C}_6\text{H}_5\text{COOH}$ is the simplest aromatic acid.

Physical properties. Ethanoic acid as a colourless liquid with a specific pungent smell and sour taste. It is completely miscible with water. Benzoic acid is a crystalline colourless substance with a peculiar smell. It is slightly soluble in water. Its solubility increases if the temperature rises.

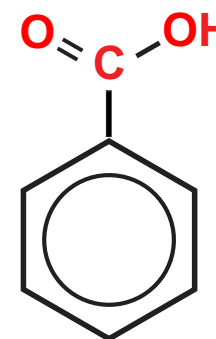
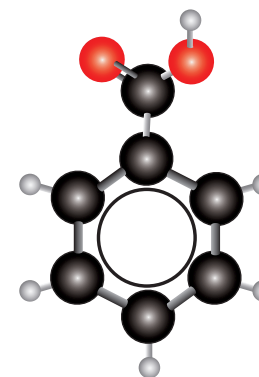
Ethanoic acid and benzoic acid are weak acids. When dissolved in water they partially dissociates liberating hydrogen cations H^+ and acidic anions CH_3COO^- (ethanoate anion) and $\text{C}_6\text{H}_5\text{COO}^-$ (benzoate anion):



Methanoic acid
 CH_3COOH

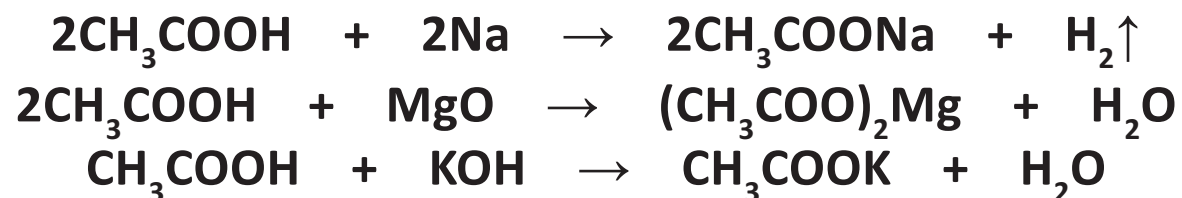


Ethanoic acid
 CH_3COOH

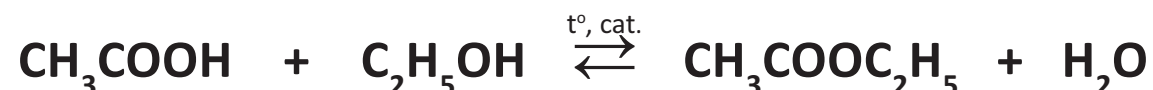


Benzoic acid
 $\text{C}_6\text{H}_5\text{COOH}$

Chemical properties. Ethanoic acid displays the common for all acids chemical properties – it reacts with **active metals**, **basic oxides** and **bases**.



The reaction of **esterification** is a typical interaction for ethanoic acid and all carboxylic acids. For example ethanoic acid reacts with ethanol, yielding an ester (ethyl ethanoate) and water:

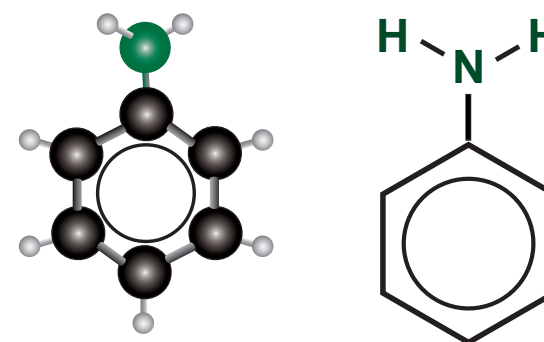


AMINES

Amines are organic compounds composed of carbon hydrogen and nitrogen. The simplest amine is methylamine **CH₃NH₂**. It contains one amino group –NH₂, the functional group of this class of organic compounds. Aminobenzene C₆H₅NH₂ is the simplest aromatic amine. It is commonly known as aniline. Methylamine CH₃NH₂ is a gas at standard conditions. Aminobenzene is a very slightly soluble in water, oily, flammable liquid with an unpleasant odour.



Methylamine CH₃NH₂



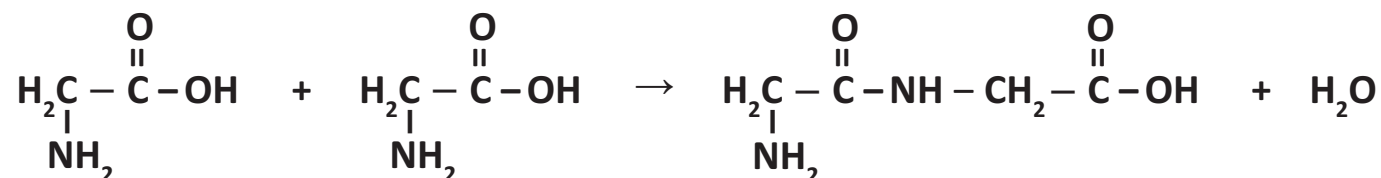
Aminobenzene C₆H₅NH₂

AMINO ACIDS

AMINO ACIDS are organic compounds with two functional groups in their molecules – a carboxyl group **-COOH** and an amino group **-NH₂**. For living organisms the most important are the α -amino acids (the **-NH₂** group is neighbour to the **-COOH** group) as they are building blocks of proteins. Many of them are known by their common names.

Physical properties. Amino acids are colourless crystalline solids. They are soluble in water but are insoluble in nonpolar solvents (e.g. benzene and other hydrocarbons).

Chemical properties. For the living world the most important chemical property of α -amino acids is the **formation of long polypeptide chains**. Molecules of α -amino acids bond to each other by peptide bonds. For example, two molecules of aminoethanoic acid (glycine) form a dipeptide.



This dipeptide can react with another molecule of aminoethanoic acid (or another α -amino acid) and so on. The long polypeptides build proteins.

$\begin{array}{c} \text{H}_2\text{C} - \text{COOH} \\ \\ \text{NH}_2 \end{array}$	Aminoethanoic acid (Glycine)
$\begin{array}{c} \text{H}_3\text{C} - \text{CH} - \text{COOH} \\ \\ \text{NH}_2 \end{array}$	2-aminopropanoic acid (Alanine)

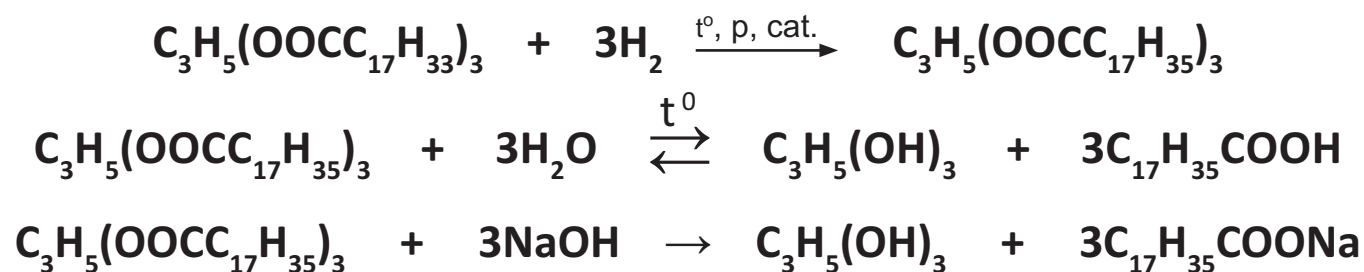
FATS

FATS are esters of fatty acids (aliphatic carboxylic acids, generally, with straight chains of uneven number (up to 23) of C atoms) and propane-1,2,3-triol (glycerol). They are also named **triglycerides** as they contain three acid residues. Some of the most important are the fatty acids with 16–18 C atoms (including the carbon atom of the –COOH group).

Physical properties. Triglycerides are solid or liquid. Solid triglycerides are esters of saturated fatty acids (palmitic $C_{15}H_{31}COOH$, stearic $C_{17}H_{35}COOH$, etc.). Generally, they are called **fats**. Liquid triglycerides are esters of unsaturated fatty acids (oleic $C_{17}H_{33}COOH$, linoleic $C_{17}H_{31}COOH$, linolenic $C_{17}H_{29}COOH$, etc.). Generally, plants triglycerides are liquid and are called **oils** – olive, linseed, sunflower, etc. Fats and oils in plants and animals are natural mixtures of different triglycerides.

Fats are insoluble in water and are lighter than water. They dissolve well in organic solvents (tetrachloromethane, petrol, etc.). Fats are poor heat conductors.

Chemical properties. Important chemical reactions of fats and oils are their **hydrogenation**, **hydrolysis** and **saponification**. For example:

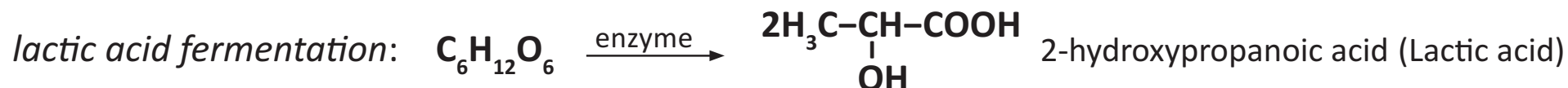
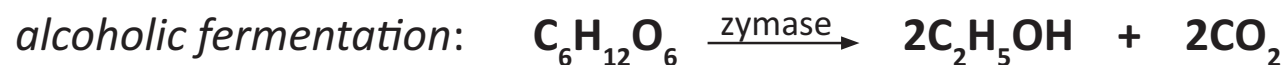


Exposed to air and under the action of sunlight, moisture and some bacteria fats and oils become rancid. The process is known as **rancidification**.

CARBOHYDRATES

CARBOHYDRATES are built up of carbon, hydrogen and oxygen. Their general formula is $C_n(H_2O)_m$. The simplest carbohydrates are the **MONOSACCHARIDES**, e.g. glucose $C_6H_{12}O_6$ (or $C_6(H_2O)_6$). It is a colourless crystalline substance with a sweet taste. It dissolves well in water. Glucose is a polyhydroxyaldehyde – it adds H_2 , oxidizes upon heating under the action of Ag_2O and $Cu(OH)_2$, reacts with $Cu(OH)_2$ also at common temperature and takes part in esterification reactions.

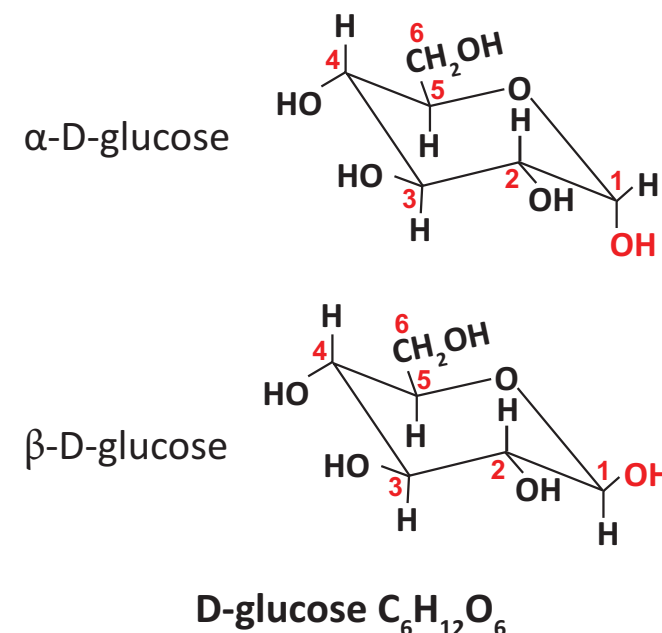
Under the action of specific enzymes glucose is transformed into alcohols or carboxylic acids:



Glucose is an energy resource for the human body. It reacts with oxygen (a reaction inverse to the photosynthesis in green plants) to liberate a significant amount of energy:



The „burning“ of glucose provides energy that is necessary to the metabolic processes. The process is catalysed by the hormone insulin.



DISACCHARIDES are carbohydrates composed of two monosaccharide residues (same or different) linked by **glycosidic linkage**. For example, **saccharose** (or white refined sugar) $C_{12}H_{22}O_{11}$ or $C_{12}(H_2O)_{11}$ is built up of an α -D-glucose and a β -D-fructose residue. Saccharose is the most common disaccharide.

POLYSACCHARIDES are long chain carbohydrates – their molecules are made up of many monosaccharides residues. In living nature the most common polysaccharides are **starch** and **cellulose**. They are biopolymers.

STARCH $(C_6H_{10}O_5)_n$ is made up of many residues of α -D-glucose bonded by glycosidic linkages. Starch is composed of **amylose** (with straight carbon chains) and **amylopectin** (with branched carbon chains). Most often starch is composed of 20–30% amylose and 70–80% amylopectin.

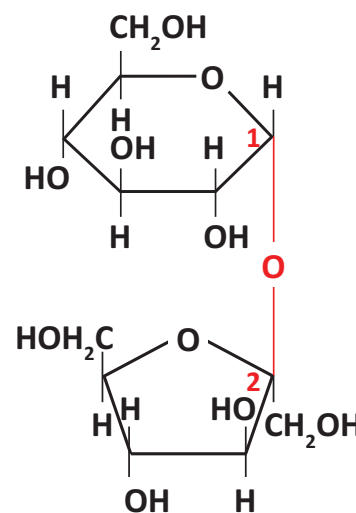
Starch is an odourless and colourless white powder. It does not really dissolve in cold water – it forms a suspension. But if heated to boiling temperature, it dissolves well.

Starch hydrolyzes under the action of enzymes (amylases) or acids. The final product is α -D-glucose.

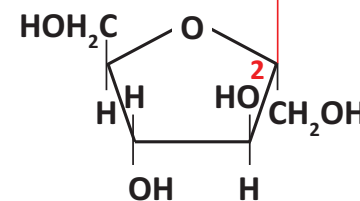
CELLULOSE $(C_6H_{10}O_5)_m$ is a solid fibrous white substance. It is made up of β -D-glucose residues. The molecules of cellulose are straight – many thousands of β -D-glucose residues are linked as in the amylose molecules. Strong intermolecular interactions keep these chains in bundles. Cellulose does not dissolve in water and may be processed to produce fibres.

The hydrolysis of cellulose is difficult as compared to the hydrolysis of starch. The process is catalytic and undergoes under heating. The final product is β -D-glucose. This process is catalyzed by specific enzymes and plants rich in cellulose are foods for many animals.

α -D-glucose residue



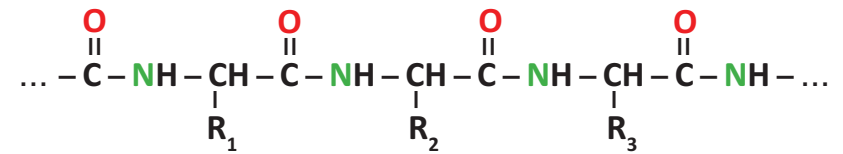
β -D-fructose residue



SACCHAROSE

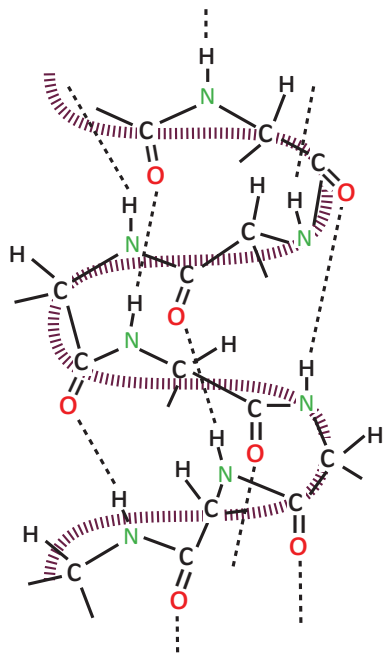
PROTEINS

PROTEINS are natural biopolymers made up of many α -amino acids residues, linked in a specific sequence by peptide bonds in **polypeptide chains**. This is the **primary structure** of proteins.



PRIMARY STRUCTURE

A POLYPEPTIDE CHAIN



SECONDARY STRUCTURE
 α -helix

The long polypeptide chains fold forming the **secondary structure** of proteins. The most common secondary structure is the so called alpha-helix. Secondary structures are local structures and many secondary structures can be present in the same protein. The final 3-dimensional compact conformation of the whole folded protein chain determines its **tertiary structure**.

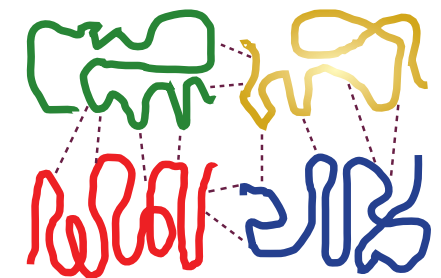
Proteins constituted of more than one polypeptide chain are also characterised by their **quaternary structure**. This is the arrangement in space of the individual folded chains relative to one another.

Proteins may be classified as **fibrous** or **globular**.

Proteins **hydrolyse** and **denaturate**. The **hydrolysis** of proteins is a catalytic process – it undergoes in the presence of acids or bases or under the action of enzymes. Heating is also needed. Hydrolysis affects the proteins primary structure. The final product is a mixture of the α -amino acids building up the polypeptide chains.



TERTIARY STRUCTURE



QUATERNARY STRUCTURE
(cluster of four polypeptide chains)

CAN YOU ANSWER THESE QUESTIONS ?

1. Why CO , CO_2 , H_2CO_3 and CaCO_3 are not organic compounds?
2. What is the difference between aliphatic and aromatic compounds?
3. The molecular formula of a hydrocarbon is C_4H_8 . What is its name?
a) butene b) cyclobutane c) either butene or cyclobutane
4. Which of the compounds is an aromatic organic compound – benzene C_6H_6 or cyclohexane C_6H_{12} ?
5. How to distinguish experimentally between an alcohol (e.g. ethanol $\text{C}_2\text{H}_5\text{OH}$) and an aldehyde (e.g. ethanal CH_3CHO)?
6. Aldehydes, ketones and carboxylic acids have >C=O groups in their molecules. Why are they different classes of organic compounds?
7. Why are carbohydrates classified as monosaccharides, disaccharides and polysaccharides?
8. Molecules of both starch and cellulose are built up of glucose residues but these polysaccharides differ in their properties. Why?
9. Why are fats and oils called also triglycerides?
10. What is common between α -amino acids and proteins?

PROJECTS

1. THE MAIN TYPES OF CHEMICAL REACTIONS

Summarise the main categories of chemical reactions. Give examples of different types of reactions in the everyday life.

2. ACIDS, BASES AND SALTS IN NATURE

Give examples of acids, bases and salts occurring in nature. What are they used for?

3. HYDROCARBONS IN NONLIVING NATURE

Find out what hydrocarbons are the most abundant in the nonliving nature? What are their most important applications? What is the impact of their use on the environment?

4. ORGANIC COMPOUNDS IN THE LIVING WORLD

Learn more about the main classes of organic compounds in plants, animal and humans. What is their role for maintaining life?