ENGLISH IN CHEMISTRY

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Spis treści

WSTĘP

Niniejszy skrypt powstał na bazie znacznie obszerniejszego podręcznika M. Kwiatkowski, P. Stepnowski "Język angielski w chemii i ochronie środowiska" i stanowi odpowiedź na zmiany w programach kształcenia studentów kierunku CHEMIA na Wydziale Chemii Uniwersytetu Gdańskiego, które zaszły w ostatnich latach. Znaczne zmniejszenie liczby godzin poświęconych na kształcenie umiejętności posługiwania się specjalistycznym językiem angielskim w zakresie chemii pociągnęło za sobą konieczność odpowiedniej redukcji zakresu tematycznego przedmiotu. Skrypt "English in Chemistry" stanowi autorską próbę dostosowania treści do nowych ram czasowych poprzez staranną selekcję tematów poszczególnych spotkań. Autorzy żywią przekonanie, że w nowej, skróconej formie, skrypt będzie stanowił użyteczną pozycję literaturową, wspomagającą kształcenie chemiczne studentów na Uniwersytecie Gdańskim.

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1. Naming Inorganic Compounds. Part I.

Naming compounds:

When chemistry was a young science and the number of known compounds was small, it was possible to memorize their names. Many of the names were derived from their physical appearance, properties, origin or application – for example, milk of magnesia, laughing gas, limestone, caustic soda, lye, washing soda, and baking soda.

Today the number of known compounds is well over 13 million. Fortunately, it is not necessary to memorize their names. Over the years chemists have devised a clear system for naming chemical substances. The rules are accepted worldwide, facilitating communication among chemists and providing a useful way of labeling an overwhelming variety of substances.

R. Chang "Chemistry" 7th Edition, McGraw-Hill, New York 2002, p. 53

1.1. Types of inorganic compounds

Chemical compounds are usually classified as inorganic or organic. Organic compounds are compounds of carbon in combination with hydrogen, oxygen, nitrogen and sulphur. All other compounds are inorganic compounds. Simple compounds of carbon, such as carbon monoxide CO or carbon dioxide CO_2 are classified as inorganic compounds, too.

There are four general categories of inorganic compounds: binary compounds with oxygen or hydrogen, acids, hydroxides and salts. The borderlines between these categories are not clear-cut. Hydrogen chloride HCl may be classified either as a binary compound with hydrogen or as an acid.

Binary compounds consist of two elements. Those containing oxygen are referred to as oxides that can be of a molecular or an ionic nature. Binary compounds with hydrogen have no separate class name.

Compounds that produce hydrogen ions H^+ in aqueous solution are typical acids. Binary acids are compounds of hydrogen with highly electronegative elements, e.g. hydrochloric acid HCl. Oxoacids contain oxygen atom(s) in their molecules, e.g. nitric acid HNO_3 or sulphuric acid H_2SO_4. Acids are also classified as monoprotic, diprotic, triprotic, etc., depending on the number of hydrogen atoms that can be removed as H^+ ions in aqueous solution.

Hydroxides are compounds of metal cations with hydroxide anions OH^-. They are ionic compounds with the general formula $M(OH)_n$. Some hydroxides are strong bases, for example, sodium hydroxide NaOH or calcium hydroxide $Ca(OH)_2$. They dissociate in aqueous solution to produce hydroxide ions. But many hydroxides are poorly soluble in water because of the partial covalent nature of the bonding and are only weak bases. Examples include copper(II) hydroxide $Cu(OH)_2$ or iron(III) hydroxide $Fe(OH)_3$.

Salts are the products of neutralization reactions between acids and bases. They are ionic compounds. The dissolution of salts in water always involves their dissociation to their component ions: hydrated cations and anions.

Table 1.1.1. Inorganic compounds of carbon

C^{4-}	carbide ion
CO	carbon monoxide
CO_2	carbon dioxide
H_2CO_3	carbonic acid
HCO_3^-	bicarbonate ion
CO_3^{2-}	carbonate ion
HCN	hydrogen cyanide
CN^-	cyanide ion
CNO^-	cyanate ion, also isocyanate ion
SCN^-	thiocyanate ion, also isothiocyanate ion
CS_2	carbon disulphide

1.1.1. *Reading comprehension*

1. Why is it impossible to memorize the common names of chemical compounds?
2. How are chemical compounds classified in general?
3. What does the term 'binary compound' mean?
4. How are acids classified?
5. Are all metal hydroxides bases?
6. How are salts formed?

1.1.2. *New terms and expressions*

acid	kwas
anaesthetic (US anesthetic)	środek znieczulający
appearance	wygląd
application	zastosowanie
baking soda	soda oczyszczona, wodorowęglan sodu $NaHCO_3$
base	zasada
bicarbonate	wodorowęglan
binary	dwuskładnikowy
binary acid	kwas beztlenowy
carbide	węglik
carbonate	węglan
carbonic acid	kwas węglowy
caustic	żrący
caustic soda	soda żrąca, wodorotlenek sodu NaOH
classify	klasyfikować, dzielić, zaliczać do
combination	połączenie
commercial	dostępny w handlu
communication	porozumiewanie (się)
cyanate, isocyanate	cyjanian, izocyjanian
cyanide	cyjanek
detergent	proszek do prania, detergent
devise	wymyślić, opracować
diprotic	dwuprotonowy
facilitate	ułatwiać
hydrated	uwodniony, hydratowany
hydrogen chloride	chlorowodór
hydrogen cyanide	cyjanowodór
hydrogen ion	jon wodorowy
hydroxide	wodorotlenek
hydroxide anion	jon wodorotlenkowy
inhalation	wdychanie, inhalacja
inorganic	nieorganiczny
labelling (US labeling)	oznakować, nadać etykietę (tu: nadać nazwę)

laughing gas	gaz rozweselający, podtlenek azotu N_2O
limestone	wapień, węglan wapnia $CaCO_3$
lye	ług (wodny roztwór mocnej zasady)
memorize	zapamiętać
mild	łagodny
milk of magnesia	wodna zawiesina wodorotlenku magnezu $Mg(OH)_2$
monoprotic	jednoprotonowy
neutralization	zobojętnienie
nitric acid	kwas azotowy
organic	organiczny
overwhelming	przeważający
oxide	tlenek
oxoacid	kwas tlenowy
physical	fizyczny
poorly	słabo
provide	zapewniać, dostarczać
rule	zasada
salt	sól
softener	zmiękczacz
sulphide (US sulfide)	siarczek
sulphuric acid (US sulfuric acid)	kwas siarkowy
thiocyanate, isothiocyanate	tiocyjanian, rodanek, izotiocyjanian
treatment	leczenie
triprotic	trójprotonowy
useful	użyteczny
variety	różnorodność
washing soda	soda, soda kalcynowana, węglan sodu Na_2CO_3
worldwide	na całym świecie

1.1.3. *Exercises*

1. Which expressions correctly describe the following compounds? Choose as many expressions as possible from the following list: binary acid, binary compound, diprotic acid, metal hydroxide, monoprotic acid, oxoacid, poorly soluble in water, readily soluble in water, salt, strong acid, strong base, triprotic acid, weak acid, weak base.

KOH	
HBr	
H_2CO_3	
NH_3	
$Cu(OH)_2$	

2. Match the common names of the substances with their descriptions.

baking soda	a mildly alkaline solution used in the treatment of indigestion
laughing gas	a strongly alkaline, caustic solution
limestone	the rocks from which, e.g. the Pieniny mountains, are formed
lye	a white powder used when baking cakes, pies etc.
milk of magnesia	a white solid used as a water softener in commercial detergents
washing soda	an inhalational anaesthetic used by dentists

1.2. Binary compounds with hydrogen

Molecular compounds of elements with hydrogen usually have traditional common names. They include such compounds as methane CH_4, ammonia NH_3 or water H_2O.

Metal compounds with hydrogen are ionic in nature: they consist of metal cations and hydride anions H^-. They are therefore classified as hydrides, for example, sodium hydride NaH or calcium hydride CaH_2.

Table 1.2.1. Common binary compounds with hydrogen

LiH	lithium hydride
NaH	sodium hydride
CaH_2	calcium hydride
B_2H_6	diborane
$NaBH_4$	sodium borohydride, sodium tetrahydroborate*
$LiAlH_4$	lithium aluminium hydride*
CH_4	methane
SiH_4	silane
NH_3	ammonia
N_2H_4	hydrazine
PH_3	phosphine
AsH_3	arsine
SbH_3	stibine
H_2O	water
H_2S	hydrogen sulphide
H_2Se	hydrogen selenide
H_2Te	hydrogen telluride
HF	hydrogen fluoride
HCl	hydrogen chloride
HBr	hydrogen bromide
HI	hydrogen iodide

*A ternary compound

1.2.1. *Reading comprehension*

1. What is the difference between binary compounds of hydrogen with metals and non-metals?
2. What name do we give to compounds of metals and hydrogen?

1.2.2. *New terms and expressions*

ammonia	amoniak
analogue (US analog)	analog
arsine	arsyna, arsenowodór
borohydride	borowodorek, tetrahydroboran
burn	palić (się)
colourless (US colorless)	bezbarwny
common name	nazwa zwyczajowa
contact	kontakt, zetknięcie
diborane	diboran
extremely	w najwyższym stopniu
flame	płomień
freely	swobodnie
hydrazine	hydrazyna
hydride	wodorek
hydrogen bromide	bromowodór (dosł. bromek wodoru)
hydrogen chloride	chlorowodór (dosł. chlorek wodoru)
hydrogen fluoride	fluorowodór (dosł. fluorek wodoru)
hydrogen iodide	jodowodór (dosł. jodek wodoru)
hydrogen selenide	selenowodór (dosł. selenek wodoru)
hydrogen sulphide	siarkowodór (dosł. siarczek wodoru)
hydrogen telluride	tellurowodór (dosł. tellurek wodoru)
ignite	zapalać (się)
irritating	drażniący
methane	metan
phosphine	fosfina, fosforowodór, fosforiak
reducing agent	reduktor (substancja redukująca)
resemble	przypominać (być podobnym do)
rot	gnić

silane	silan
soluble	rozpuszczalny
solution	roztwór
stibine	stybina, antymonowodór
ternary	trójskładnikowy
toxic	trujący
water	woda

1.2.3. *Exercise*

1. Give the names of the following hydrogen compounds:

A colourless gas with an irritating odour, freely soluble in water, producing an alkaline solution.	
A gas of very unpleasant smell, toxic, ignites on contact with air.	
A colourless gas with an irritating odour, freely soluble in water, producing a strongly acidic solution; decomposes at high temperatures to give a violet gas.	
An extremely toxic gas with an unpleasant smell resembling that of rotten eggs.	
A heavier analogue of methane.	
A common reducing agent in organic chemistry.	
Burns with a green flame.	

1.3. Metal oxides and hydroxides

Binary compounds of elements with oxygen are termed ‘oxides’. Metal oxides are generally ionic compounds. They are named by giving first the name of the metal and then 'oxide', for example, magnesium oxide MgO or aluminium oxide Al_2O_3. If one metal can form more than one type of oxide, the charge on the metal cation (or the valence of the metal) is specified in parentheses just after the metal name (no space!), e.g. manganese(II) oxide MnO and manganese(III) oxide Mn_2O_3. In older nomenclature, metal ions with fewer positive charges were given the ending *–ous*, and those with more positive charges the ending *–ic*. Accordingly, iron(II) oxide FeO and iron(III) oxide Fe_2O_3 were named ferrous oxide and ferric oxide respectively. For oxidation states of four and more, metal oxides were named by placing prefixes *di*-, *tri*- etc. before 'oxide', for example, manganese dioxide MnO_2 or vanadium pentoxide V_2O_5.

Table 1.3.1. Traditional names of common metal ions according to the older nomenclature

Co^{2+}	cobalt(II)	cobaltous
Cr^{3+}	chromium(III)	chromic
Cu^{+}	copper(I)	cuprous
Cu^{2+}	copper(II)	cupric
Fe^{2+}	iron(II)	ferrous
Fe^{3+}	iron(III)	ferric
Hg^{2+}	mercury(II)	mercuric
Hg_2^{2+}	mercury(I)	mercurous
Mn^{2+}	manganese(II)	manganous
Pb^{2+}	lead(II)	plumbous
Sn^{2+}	tin(II)	stannous

Names of metal hydroxides are derived in a similar way, by placing 'hydroxide' after the name of the metal ion, e.g. potassium hydroxide KOH, calcium hydroxide $Ca(OH)_2$, or iron(III) hydroxide $Fe(OH)_3$ (ferric hydroxide). Hydroxides of alkali metals and alkaline earth metals are strong bases, wheras those of other metals exhibit only weakly basic properties. Some hydroxides, such as aluminium or zinc hydroxides are amphoteric: they react with both acids and bases to give the corresponding salts.

1.3.1. *Reading comprehension*

1. How are binary compounds of metals and oxygen named?
2. What are the other names of copper(I) and copper(II) oxides?
3. What is the name of the OH^- ion?
4. What does it mean that $Al(OH)_3$ is amphoteric?

1.3.2. *New terms and expressions*

accordingly	zgodnie z powyższym
amphoteric	amfoteryczny
chromic	chromowy
cobaltous	kobaltawy
corresponding	odpowiedni, odpowiadający
cupric	miedziowy
cuprous	miedziawy
dioxide	dwutlenek
excess	nadmiar
ferric	żelazowy
ferrous	żelazawy
manganous	manganawy
mercuric	rtęciowy
mercurous	rtęciawy
oxidation state	stopień utlenienia
parentheses	nawiasy
pentoxide	pięciotlenek
plumbous	ołowiawy
precipitate	osad
prefix	przedrostek
space	spacja
specify	podać, określić, wyszczególnić
stannous	cynawy
valence	wartościowość

1.3.3. *Exercises*

1. Give all the possible names of the following oxides and hydroxides:

$Al(OH)_3$	
$Cr(OH)_3$	
CrO_3	
Cu_2O	
Hg_2O	
HgO	
$Mn(OH)_2$	
NaOH	
TiO_2	
ZnO	

2. Fill in the blanks:

The addition of .... NaOH to a solution of a zinc salt produces a white precipitate of .... $Zn(OH)_2$. The precipitate .... in an excess of the reagent. It is also soluble in .... HCl. This means that $Zn(OH)_2$ is ....

2. Naming Inorganic Compounds. Part II.

2.1. The oxides of non-metals

The oxides of non-metals are covalent compounds, usually with a molecular structure, for example, sulphur dioxide SO_2 or phosphorus pentoxide P_4O_{10}. Some of them, such as silicon dioxide SiO_2, form giant macromolecular structures.

The names of these compounds are formed by indicating the number of oxygen atoms linked to the non-metal atom in the molecule rather than by specifying the oxidation state of the non-metal. So the compound NO is called nitrogen monoxide rather than nitrogen(II) oxide and SO_3 is sulphur trioxide rather than sulphur(VI) oxide. The names of the most common non-metal oxides are listed below. Note how the oxides of elements in an odd-numbered oxidation state used to be named in the older nomenclature.

Table 2.3.1. Names of common non-metal oxides

Oxide	**Systematic name**	**Other names**
CO	carbon monoxide	carbonic oxide, coal gas
CO_2	carbon dioxide	dry ice (solid)
N_2O	dinitrogen monoxide	nitrous oxide, laughing gas
NO	nitrogen monoxide	nitric oxide
N_2O_3	dinitrogen trioxide	nitrogen trioxide
NO_2	nitrogen dioxide	
N_2O_4	dinitrogen tetroxide	nitrogen tetroxide, nitrogen peroxide
N_2O_5	dinitrogen pentoxide	nitrogen pentoxide
OF_2	oxygen fluoride	
SiO_2	silicon dioxide	
P_4O_{10}	tetraphosphorus decaoxide	phosphorus pentoxide, phosphorus(V) oxide
SO_2	sulphur dioxide	sulphur(IV) oxide
SO_3	sulphur trioxide	sulphur(VI) oxide
Cl_2O	dichlorine monoxide	
ClO_2	chlorine dioxide	
Cl_2O_7	dichlorine heptoxide	chlorine(VII) oxide

Many non-metal oxides are acid anhydrides, since they react with water to produce acids. Here are two examples:

$$\underset{\text{sulphur trioxide}}{SO_3(g)} + \underset{\text{water}}{H_2O(l)} \rightarrow \underset{\text{sulphuric acid}}{H_2SO_4(aq)}$$

$$\underset{\text{dinitrogen pentoxide}}{N_2O_5(g)} + \underset{\text{water}}{H_2O(l)} \rightarrow \underset{\text{nitric acid}}{2\ HNO_3(aq)}$$

2.1.1. *Reading comprehension*

1. What is the difference between metal oxides and non-metal oxides?
2. Do we usually specify the oxidation state of a non-metal when naming its oxide?

2.1.2. *New terms and expressions*

(The Polish terms for most of the specific compounds are omitted).

anhydride	bezwodnik
carbon monoxide	tlenek węgla (czad)
chemical equation	równanie reakcji chemicznej
dioxide	dwutlenek
engine	silnik
exhaust	spaliny, rura wydechowa
harmful	szkodliwy
incomplete	niezupełny, częściowy
macromolecular	wielkocząsteczkowy
monoxide	tlenek (monotlenek)
odd (odd-numbered)	nieparzysty
oxidize	utleniać
pentoxide	pięciotlenek
petrol (US gasoline)	benzyna
radical	rodnik
source	źródło
tetroxide	czterotlenek
trioxide	trójtlenek
vapour (US vapor)	para (stan gazowy)

2.1.3. *Exercise*

1. Fill in the blanks.

Car engines use petrol as the source of .... Burning petrol produces chiefly .... gas and .... vapour, but car engines also produce other, harmful .... At the high temperature of a working engine, the constituents of the air react with one another to form toxic .... This is readily oxidized in air to brown ...., which in turn reacts with oxygen to give ozone, a source of free radicals. The incomplete combustion of fuel produces extremely toxic .... The traces of sulphur contained in fuel are the source of the .... emitted together with the exhaust gases.

2.2. Acids and their anions.

Some binary compounds of non-metals behave like acids in aqueous solution. For example, an aqueous solution of hydrogen chloride is a strong acid, so it is termed hydrochloric acid. The names of other binary acids are derived in a similar way. The names of the anions formed by binary acids end in *–ide*: so the anion of hydrochloric acid is the chloride ion Cl^-, that of hydrosulphuric acid is the sulphide ion S^{2-}, etc.

The names of oxoacids are formed by adding *–ic* to the name of the central element, e.g. sulphuric acid H_2SO_4 or chloric acid $HClO_3$. The names of the anions formed by such acids end in *–ate*: sulphate SO_4^{2-}, chlorate ClO_3^-.

Often, the central element of an oxoacid can exist in several oxidation states, giving rise to a number of different oxoacids. The rules for naming such acids and their anions are as follows:

Number of oxygen atoms compared to the *–ic* acid	**Prefix (acid and anion)**	**Ending (acid)**	**Ending (anion)**	**Example**
one more	*per-*	*-ic*	*-ate*	perchloric acid $HClO_4$ perchlorate anion ClO_4^-
the same		*-ic*	*-ate*	chloric acid $HClO_3$ chlorate anion ClO_3^-
one less		*-ous*	*-ite*	chlorous acid $HClO_2$ chlorite anion ClO_2^-
two less	*hypo-*	*-ous*	*-ite*	hypochlorous acid HClO hypochlorite anion ClO^-

The more modern naming system, using the ending *–ate* for all oxoacids and giving the oxidation state of the central element as a Roman numeral, is still in limited use in English nomenclature. For example, sulphuric acid and sulphurous acid are usually preferred to sulphuric(VI) acid and sulphuric(IV) acid.

2.2.1. *Reading comprehension*

1. What acid is formed when hydrogen chloride is dissolved in water?
2. What are the salts of hydrosulphuric acid called?
3. What are the names of the oxoacids formed by chlorine?
4. Why do you think the modern names of sulphurous and sulphuric acid may be confusing?

Table 2.2.1. The names of common acids and their anions. The names according to the modern nomenclature are given only when they differ from those in the older nomenclature.

Acid	Name (old)	Name (modern)	Anion	Name (old)	Name (modern)
			B^{3-}	boride	
H_3BO_3	boronic		BO_3^{3-}	borate	
			C^{4-}	carbide	
H_2CO_3	carbonic		CO_3^{2-}	carbonate	
			N^{3-}	nitride	
HNO_2	nitrous	nitric(III)	NO_2^-	nitrite	nitrate(III)
HNO_3	nitric	nitric(V)	NO_3^-	nitrate	nitrate(V)
HF	hydrofluoric		F^-	fluoride	
			$[Al(OH)_4]^-$	aluminate	
			Si^{4-}	silicide	
H_2SiO_3	silicic		SO_3^{2-}	silicate	
			P^{3-}	phosphide	
H_3PO_3	phosphorous	phosphoric(III)	PO_3^{3-}	phosphite	phosphate(III)
H_3PO_4	phosphoric	phosphoric(V)	PO_4^{3-}	phosphate	phosphate(V)
H_2S	hydrosulphuric		S^{2-}	sulphide	
H_2SO_3	sulphurous	sulphuric(IV)	SO_3^{2-}	sulphite	sulphate(IV)
H_2SO_4	sulphuric	sulphuric(VI)	SO_4^{2-}	sulphate	sulphate(VI)
HCl	hydrochloric		Cl^-	chloride	
HClO	hypochlorous	chloric(I)	ClO^-	hypochlorite	chlorate(I)
$HClO_2$	chlorous	chloric(III)	ClO_2	chlorite	chlorate(III)
$HClO_3$	chloric	chloric(V)	ClO_3^-	chlorate	chlorate(V)
$HClO_4$	perchloric	chloric(VII)	ClO_4^-	perchlorate	chlorate(VII)
			$[Cr(OH)_4]^-$	chromite	chromate(III)
			CrO_4^{2-}	chromate	chromate(VI)
			$Cr_2O_7^{2-}$	dichromate	dichromate(VI)
			MnO_4^{2-}	manganate	manganate(VI)
			MnO_4^-	permanganate	manganate(VII)
H_3AsO_3	arsenous	arsenic(III)	AsO_3^{3-}	arsenite	arsenate(III)
H_3AsO_4	arsenic	arsenic(V)	AsO_4^{3-}	arsenate	arsenate(IV)
HBr	hydrobromic		Br^-	bromide	
HBrO	hypobromous	bromic(I)	BrO^-	hypobromite	bromate(I)
$HBrO_2$	bromous	bromic(III)	BrO_2^-	bromite	bromate(III)
$HBrO_3$	bromic	bromic(V)	BrO_3^-	bromate	bromate(V)
$HBrO_4$	perbromic	bromic(VII)	BrO_4^-	perbromate	bromate(VII)
			MoO_4^{2-}	molybdate	molybdate(VI)
			SnO_3^{2-}	stannate	stannate(VI)
HI	hydriodic		I^-	iodide	
HIO	hypoiodous	iodic(I)	IO^-	hypoiodite	iodate(I)
HIO_2	iodous	iodic(III)	IO_2^-	iodite	iodate(III)
HIO_3	iodic	iodic(V)	IO_3^-	iodate	iodate(V)
HIO_4	periodic	iodic(VII)	IO_4^-	periodate	iodate(VII)
			PbO_3^{2-}	plumbate	plumbate(IV)

2.2.2. *New terms and expressions*

(The Polish terms for most of the specific compounds are omitted).

hydro................ic acid	kwas ....wodorowy (wyj. kwas solny)
..................ide	...................ek (sól kwasu beztlenowego)
.......................ic acid	kwas ....owy
......................ate	...................an (sól kwasu tlenowego)
per...................ic acid	kwas nad....................owy
per...................ate	nad......................an (sól kwasu tlenowego)
......................ous acid	kwas ....awy
......................ite	...................yn (sól kwasu tlenowego)
hypo...................ous acid	kwas pod......................awy
hypo..................ite	pod..............yn (sól kwasu tlenowego)
Roman numeral	cyfra rzymska
still	wciąż

2.2.3. *Exercise*

1. Give the names of the following compounds.

an acid producing a Cl^- ion in aqueous solution	
the anions formed when chlorine is dissolved in alkaline solution	
a binary acid formed by iodine	
heavier analogues of the MnO_4^- ion	
the NO_2^- ion	
oxoacids of bromine in the lowest and in the highest oxidation state	
oxoacids of sulphur	

2.3. Salts

Salts are named by first giving the name of the cation and then the name of the anion. Examples are magnesium bromide $MgBr_2$, iron(III) sulphate $Fe_2(SO_4)_3$ or ammonium dichromate $(NH_4)_2Cr_2O_7$.

Polyprotic acids may form anions by losing one, two, etc. hydrogen ions respectively. In this case, the number of hydrogen atoms left in the anion is indicated in this name. For example, phosphoric acid H_3PO_4 can form three types of anions: dihydrogen phosphate $H_2PO_4^-$, hydrogen phosphate HPO_4^{2-} and phosphate PO_4^{3-}. The salts are named accordingly.

In the case of salts containing more than two types of cations, all the ions are specified in the name: potassium aluminium sulphate $KAl(SO_4)_2$ or calcium magnesium carbonate $CaMg(CO_3)_2$. Hydrated salts contain water incorporated in the crystal lattice. The specific number of water molecules in the salt formula is indicated by the appropriate description: dihydrate, trihydrate, etc. Copper(II) sulphate pentahydrate $CuSO_4 \cdot 5H_2O$ is blue, while anhydrous $CuSO_4$ is white.

2.3.1. *Reading comprehension*

1. How are the names of salts formed?
2. What do we call the compound $MgSO_4$?
3. What are the names of the salts NaH_2PO_4 and K_2HPO_4?
4. What colour change takes place when hydrated copper sulphate is heated?

Table 2.3.1. Common anions containing hydrogen atoms.

HCO_3^-	hydrogen carbonate, bicarbonate
$H_2PO_4^-$	dihydrogen phosphate
HPO_4^{2-}	hydrogen phosphate
HS^-	hydrogen sulphide, bisulphide
HSO_3^-	hydrogen sulphite, bisulphite
HSO_4^-	hydrogen sulphate, bisulphate

Table 2.3.2. Examples of hydrated salts

$LiCl \cdot H_2O$	lithium chloride monohydrate
$CaSO_4 \cdot 2\ H_2O$	calcium sulphate dihydrate, gypsum
$K_2HPO_4 \cdot 3\ H_2O$	potassium hydrogen phosphate trihydrate
$FeCl_2 \cdot 4\ H_2O$	iron(II) chloride tetrahydrate, ferrous chloride tetrahydrate
$CuSO_4 \cdot 5\ H_2O$	copper(II) sulphate pentahydrate, cupric sulphate pentahydrate, bluestone
$NiSO_4 \cdot 6\ H_2O$	nickel(II) sulphate hexahydrate
$MgSO_4 \cdot 7\ H_2O$	magnesium sulphate heptahydrate, Epsom salt
$Na_2CO_3 \cdot 10\ H_2O$	sodium carbonate decahydrate, washing soda

2.3.2. *New terms and expressions*

(The Polish terms for most of the specific compounds are omitted)

bi......................ate	wodoro...............an
bi......................ide	wodoro................ek
hydrogen ....ate	wodoro.................an
hydrogen ....ide	wodoro.................ek
dihydrogen ....ate	diwodoro......................an
polyprotic	wieloprotonowy
ammonium	amonu, amonowy
bluestone	siny kamień
contain	zawierać
description	opis
Epsom salt	sól angielska, epsomit
gypsum	gips
hydrate	hydrat
hydrated	uwodniony, hydratowany

2.3.3. *Exercises*

1. Give the names of the following salts.

FeS	
$FeSO_4$	
$CuCr_2O_7$	
$LiIO_4$	
Hg_2Br_2	
KH_2PO_4	
$NaHSO_3$	
$AlF_3 \cdot H_2O$	
$NH_4Al(SO_4)_2 \cdot 12H_2O$	

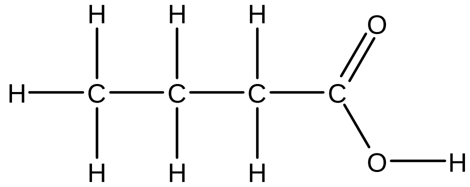
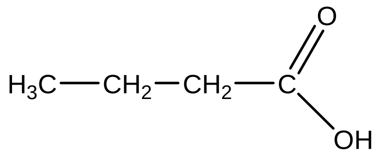
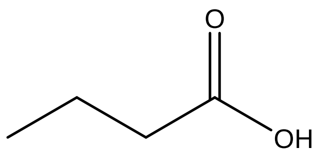
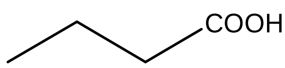
2. Give the names of salts according to their colour, then give their formulae. Choose your answers from the following list: chromium(III) nitrate nonahydrate, cobaltous chloride dihydrate, copper(II) sulphate pentahydrate, ferric chloride hexahydrate, ferrous chloride tetrahydrate, iron(III) ammonium sulphate dodecahydrate, manganese(II) nitrate tetrahydrate, nickel chloride hexahydrate, potassium dichromate, potassium permanganate, sodium chromate

Colour		**Name**	**Formula**
	deep purple		
	dark blue		
	blue		
	green		
	pale green		
	yellow		
	orange		
	deep red		
	pink		
	pale pink, rose		
	violet		

3. Organic Molecules

3.1. Chemical formulae

Organic compounds are usually molecular compounds. Chemists represent molecules graphically as formulae. There are several types of chemical formulae:

<table>
<tr><td colspan="2">Empirical formula – this gives the ratio of atoms expressed as the smallest whole number, e.g. C_2H_4O</td></tr>
<tr><td colspan="2">Molecular formula – this gives the actual numbers of all the atoms in the molecule, e.g. $C_4H_8O_2$</td></tr>
<tr><td colspan="2">Structural formula – this shows how the atoms are connected (but does not represent the actual shape of the molecule!). There are three types of structural formula:</td></tr>
<tr><td>Expanded formula
All the bonds are shown as dashes and all the atoms are shown as symbols.</td><td></td></tr>
<tr><td>Condensed formula
Not all the bonds are shown; the atoms are shown in groups.</td><td>
$CH_3CH_2CH_2–COOH$ $CH_3(CH_2)_2COOH$ $C_3H_7CO_2H$</td></tr>
<tr><td>Skeletal structures (bond-line formulae)
Only the carbon skeleton and heteroatoms are shown.</td><td> </td></tr>
<tr><td colspan="2">General formula – this gives the general ratio of atoms in a family of compounds: $C_nH_{2n+1}COOH$</td></tr>
</table>

All the above formulae represent the same compound: butanoic acid

3.1.1. *Reading comprehension*

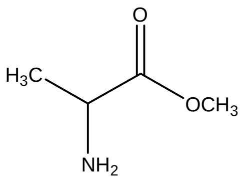
1. How do chemists represent molecules?
2. What is the difference between an empirical formula and a molecular formula?
3. Which types of formulae show how atoms are linked by chemical bonds?
4. How do skeletal structures represent organic molecules?
5. What is general formula of aliphatic alcohols?

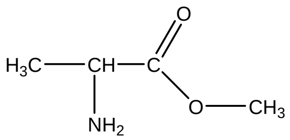
3.1.2. *New terms and expressions*

formula, formulae (formulas)	wzór, wzory (chemiczny, -ne)
empirical formula	wzór empiryczny
molecular formula	wzór sumaryczny
structural formula	wzór strukturalny
expanded formula	pełny wzór strukturalny
condensed formula	uproszczony wzór strukturalny
skeletal structure	wzór szkieletowy
bond-line formula	wzór szkieletowy
general formula	wzór ogólny
actual	rzeczywisty
alcohol	alkohol
aliphatic	alifatyczny
connectivity	sposób łączenia się ze sobą
dash	kreska
graphically	graficznie
molecular	cząsteczkowy, złożony z cząsteczek
represent	przedstawiać
skeleton	szkielet
whole number	liczba całkowita

3.2.3. *Exercises*

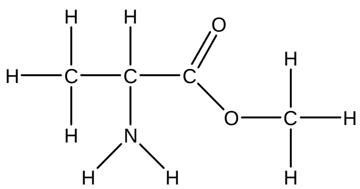
1. Match the type of formula to each representation of the alanine methyl ester molecule.

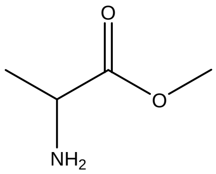




$CH_3CH(NH_2)COOCH_3$

$C_4H_9O_2N$





empirical formula

molecular formula

expanded formula

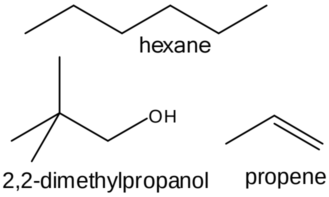
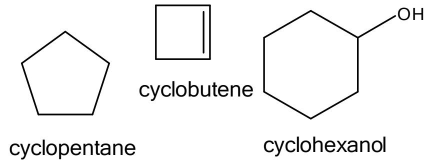
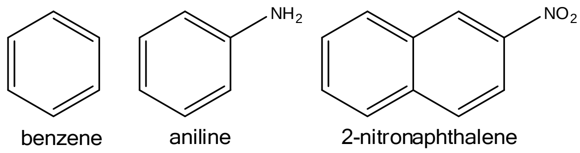
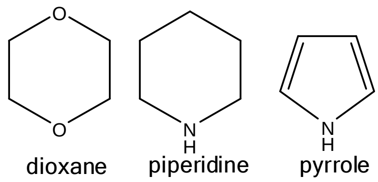
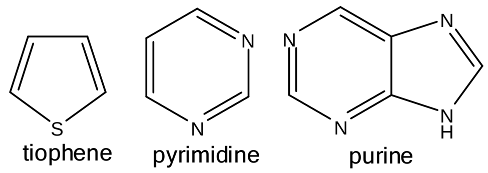
condensed formula

skeletal structure

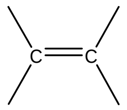
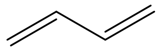
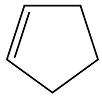
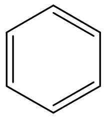
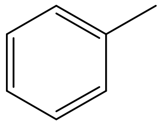
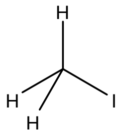
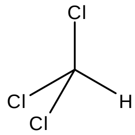
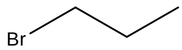
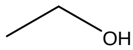
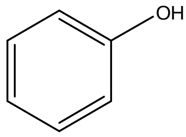
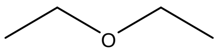
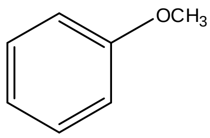
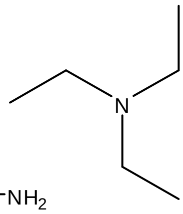
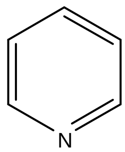
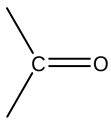
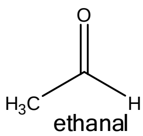
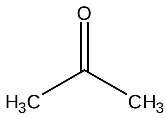
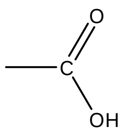
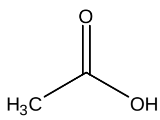
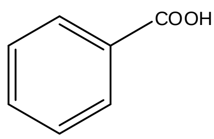
3.2. Classification of organic molecules

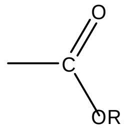
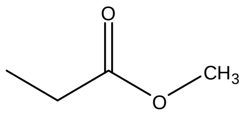
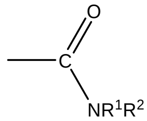
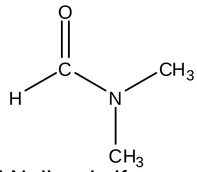
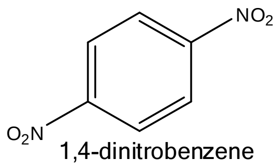
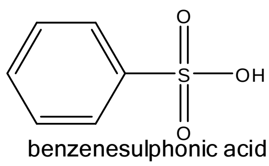
In general, organic molecules are classified according to their specific structural features. The overall shape of the carbon backbone and the presence of functional groups are two of the most important criteria.

The carbon backbone classification is shown in the table below:

Category	**Description**	**Examples**
Aliphatic	Contains a straight or a branched chain of carbon atoms.	
Alicyclic	Contains at least one ring of carbon atoms; the π electrons **are not** delocalized over the ring.	
Aromatic	Contains at least one ring of carbon atoms; the π electrons **are** delocalized over the ring.	
Heterocyclic	Contains a ring in which at least one atom is not a carbon atom.	
Heteroaromatic	Contains a ring in which at least one atom is not a carbon atom; the π electrons are delocalized over the ring.	

A functional group is a group of a few atoms that gives a compound a particular set of properties. For example, the presence of the carboxyl group COOH in the molecule implies that the compound has weak acidic properties, that it reacts with a strong alkali to give carboxylate salts and that it produces esters on reaction with alcohols. Therefore, all compounds having a carboxyl group in the molecule are included in the family of carboxylic acids. Similarly, the presence of a hydroxyl group gives rise to the family of alcohols, etc. The most common functional groups and the corresponding families of compounds are specified below:

Group	Name	Family of compounds	Examples
	double bond	alkenes, cycloalkenes, unsaturated compounds	 butadiene  cyclopentene
-C≡C-	triple bond	alkynes, unsaturated compounds	$HC\equiv CH$ ethyne
	benzene ring	arenes	 toluene
-F -Cl -Br -I	halogen (fluorine, chlorine, bromine, iodine)	haloalkanes (fluoro-, chloro-, bromo-, iodoalkanes)	 iodomethane  chloroform  1-bromopropane
-OH	hydroxyl group	alcohols, phenols	 ethanol  phenol
-OR	alkoxyl group	ethers	 diethyl ether  anisole
$-NH_2$ $-NHR^1$ $-NR^1R^2$	amine group	amines	$H_3C—NH_2$ methylamine  triethylamine  pyridine
	carbonyl group	aldehydes (COH), ketones (COR)	 ethanal  propanone
	carboxyl group	carboxylic acids	 ethanoic acid  benzoic acid

	ester group	esters	 methyl propanoate
	amide group	amides	 N,N-dimethylformamide
-C≡N	nitrile (cyano) group	nitriles	$H_3C-C\equiv N$ ethanenitrile
$-NO_2$	nitro group	nitro compounds	 1,4-dinitrobenzene
$-SO_3H$	sulpho group	sulphonic acids	 benzenesulphonic acid

3.2.1. *Reading comprehension*

1. What are the most important criteria in the classification of organic molecules?
2. How do we classify compounds that do not contain a ring in their molecules?
3. What is the difference between alicyclic and aromatic compounds?
4. What is the functional group of alkenes?
5. How do we classify compounds that have an alkoxyl group in their molecules?
6. Which categories of compounds contain a nitrogen atom in their molecules?

3.2.2. *New terms and expressions*

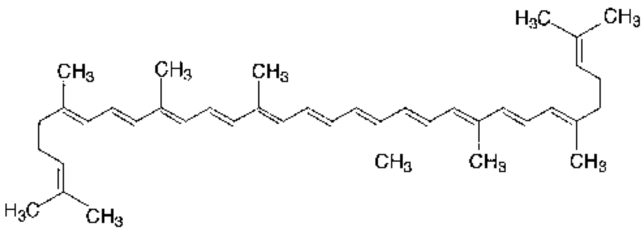
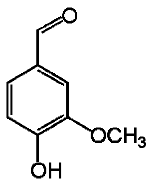
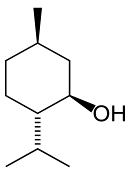
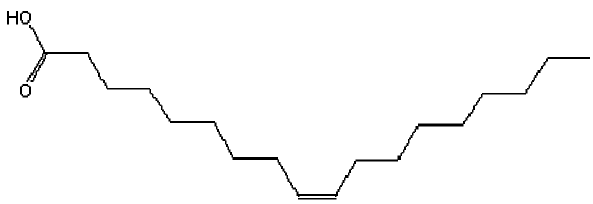
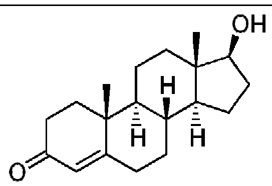
active	czynny
aldehyde	aldehyd
alicyclic	alicykliczny
aliphatic	alifatyczny
alkaloid	alkaloid
alkene	alken
alkoxyl group	grupa alkoksylowa, eterowa

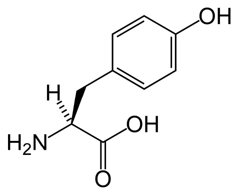
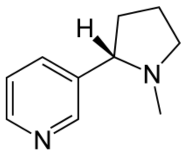
alkyne	alkin
amide	amid
amide group	ugrupowanie amidowe
amine	amina
amine group	grupa aminowa
arene	aren, pochodna benzenu
aromatic	aromatyczny
at least	co najmniej
benzene	benzen
branched	rozgałęziony
carbon backbone	szkielet węglowy (dosł. kręgosłup)
carbonyl group	grupa karbonylowa
carboxyl group	grupa karboksylowa
carboxylate	karboksylan, anion kwasu karboksylowego
carboxylic acid	kwas karboksylowy
chain	łańcuch
criterion, criteria	kryterium
cycloalkene	cykloalken
dye	barwnik
ester	ester
ester group	ugrupowanie estrowe
ether	eter
excrete	wydzielać
family	rodzina, grupa
feature	cecha, właściwość
fragrant	pachnący
functional group	grupa funkcyjna
gland	gruczoł
haloalkane	halogenoalkan, halogenek alkilowy
heteroaromatic	heteroaromatyczny
heterocyclic	heterocykliczny
hormone	hormon
hydroxyl group	grupa hydroksylowa
ketone	keton

lycopene	likopen
menthol	mentol
nicotine	nikotyna
nitrile	nitryl
nitrile group	grupa nitrylowa
nitro compound	nitrozwiązek
nitro group	grupa nitrowa
oleic acid	kwas olejowy
peppermint	mięta (pieprzowa)
phenol	fenol
plant	roślina
pod	strąk
precursor	prekursor
ring	pierścień
sex	płeć, płciowy
straight-line	prosty (nierozgałęziony)
sulpho group	grupa sulfonowa
sulphonic acid	kwas sulfonowy
testosterone	testosteron
thyroid	tarczyca
tobacco	tytoń
triglyceride	trigliceryd
tyrosine	tyrozyna
unsaturated compound	związek nienasycony
vanillin	wanilina

3.2.3. *Exercise*

1. Classify the following compounds according to the structure of their carbon backbone, the presence of functional groups and the family of chemical compounds.

Formula	**Classification**
 **lycopene**, the red-orange dye found in tomatoes	
 **vanillin**, the pleasantly smelling component of vanilla pods	
 **menthol**, the fragrant component of peppermint	
 **oleic acid**, a constituent of the triglycerides found in vegetable oil	
 **testosterone**, the male sex hormone	

 **tyrosine**, an important active precursor of hormones excreted by the thyroid gland.	
 **nicotine**, an alkaloid found in the tobacco plant	

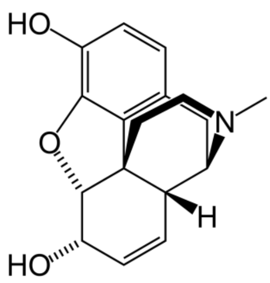
4. Naming Organic Compounds

4.1. IUPAC rules for naming organic compounds

Organic compounds are named according to a set of rules devised by the International Union of Pure and Applied Chemistry (IUPAC) and accepted all over the world. In adherence to these rules, every compound is given its own, unique name derived from the structural features of the molecule. The IUPAC system views an organic molecule as a carbon skeleton with functional groups attached at specified positions. The following steps allow any organic compound to be given a systematic name, comprehensible to every chemist worldwide:

1. Identify the carbon skeleton of the molecule and name it after the parent hydrocarbon of identical number and arrangement of carbon atoms.
2. Identify functional groups and alkyl substituents attached to the skeleton, and account for their presence in the name of the compound.
3. Recognize the priority of functional groups.
4. Use the appropriate numbering scheme to give the position of every functional group and alkyl substituent, unless it is explicit.

Systematic names may be quite complex and awkward in use. No wonder that for the sake of simplicity, chemists still use common names. Just compare the systematic and common names of the following compound:



Systematic name: 7,8-didehydro-4,5-epoxy-17-methylmorphinan-3,6-diol

Common name: morphine

4.1.1. *Reading comprehension*

1. What is the name of the organization that devised rules for the systematic naming of organic compounds?
2. How do IUPAC naming rules view an organic molecule?
3. How would you outline the IUPAC approach to naming organic compounds?
4. Why are the common names of organic compounds still in use?

4.1.2. *New terms and expressions*

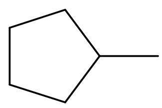
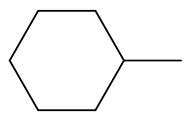
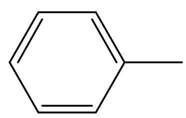
according to	zgodnie z
account for	wykazać, wciąć pod uwagę
adherence	przyleganie, tu: postępowanie zgodne z
arrangement	układ, ułożenie
attach	przyłączyć, przytwierdzić
awkward	niezręczny, dziwny, trudny
comprehensible	zrozumiały
devise	opracować, wymyślić
explicit	oczywisty, jednoznaczny
for the sake of	ze względu na
morphine	morfina
no wonder	nic dziwnego
numbering	numerowanie
parent hydrocarbon	węglowodór macierzysty
priority	pierwszeństwo
recognize	rozpoznać
rule	zasada, prawo, reguła
set	zestaw, zespół
simplicity	prostota
substituent	podstawnik
view	tu: postrzegać

Table 4.1.1. Systematic names of parent hydrocarbons

No. of C atoms	Alkanes		Cycloalkanes		Arenes	
	formula	name	formula	name	formula	name
1	CH_4	methane	---	---	---	---
2	C_2H_6	ethane	---	---	---	---
3	C_3H_8	propane	C_3H_6	cyclopropane	---	---
4.	C_4H_{10}	butane	C_4H_8	cyclobutane	---	---
5.	C_5H_{12}	pentane	C_5H_{10}	cyclopentane	---	---
6.	C_6H_{14}	hexane	C_6H_{12}	cyclohexane	C_6H_6	benzene
7.	C_7H_{16}	heptane	C_7H_{14}	cycloheptane	---	---
8	C_8H_{18}	octane	C_8H_{16}	cyclooctane	---	---
9.	C_9H_{20}	nonane	C_9H_{18}	cyclononane	---	---
10.	$C_{10}H_{22}$	decane	$C_{10}H_{20}$	cyclodecane	$C_{10}H_8$	naphthalene

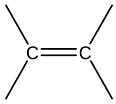
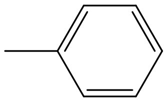
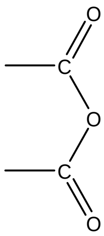
Table 4.1.2. Names of alkyl, cycloalkyl and aryl groups*

Group	Name
CH_3–	methyl
CH_3CH_2–	ethyl
$CH_3CH_2CH_2$–	propyl
$(CH_3)_2CH$–	isopropyl, *iso*-propyl
$CH_3CH_2CH_2CH_2$–	butyl, *n*-butyl
$(CH_3CH_2)(CH_3)CH$–	*sec*-butyl, *s*-butyl
$(CH_3)_3C$–	*tert*-butyl, *t*-butyl

Group	Name
	cyclopentyl
	cyclohexyl
	phenyl

*Alkyl (cycloalkyl, aryl) groups are always listed in alphabetical order.

Table 4.1.3. Names (prefixes and/or suffixes) of common functional groups.

Class of compound	Functional group	Prefix	Suffix	Example
alkene (cycloalkene)		---	-ene	cyclopentene
alkynes	–C≡C–	---	-yne	propyne
arenes		phenyl-	-benzene	ethylbenzene
fluoroalkanes*	–F	fluoro-	---	1,2-difluoropropane
chloroalkanes*	–Cl	chloro-	---	1,1,1-trichloroethane
bromoalkanes*	–Br	bromo-	---	bromocyclopentane
iodoalkanes*	–I	iodo-	---	iodobenzene
alcohols, phenols	–OH	hydroxy-	-ol	butan-2-ol
ethers	–OR	alkoxy- (methoxy-, ethoxy-, etc.)	---	methoxyethane
primary amines	$–NH_2$	amino-	-amine	aminoethane, ethylamine
secondary amines	–NHR	N-alkylamino-	-amine	N-methylamino-methane, dimethylamine
tertiary amines	–NRR'	N-alkyl-N--alkylamino-	-amine	N-ethyl-N-methylaminopropane, ethylmethylpropyl-amine
nitro compounds	$–NO_2$	nitro-	---	1,3-dinitrobenzene
aldehydes	–CHO	---	-al	butanal
ketones	–C(O)R	oxo-	-one	butanone
carboxylic acids	–COOH	---	-oic acid	propanoic acid
acyl chlorides	–COCl	---	-oyl chloride	propanoyl chloride
acid anhydrides		---	-oic anhydride	ethanoic anhydride
esters	–COOR	alkyl -oate		methyl propanoate

primary amides	$-COONH_2$	---	-amide	propanamide
secondary and tertiary amides	$-COONHR$ $-COONRR'$	N-alkyl-(N-alkyl')- -amide		N-ethylpropanamide
nitriles	$-C\equiv N$	cyano-	-nitrile	butanenitrile
sulphonic acids	$-SO_3H$	---	-sulphonic acid	toluenesulphonic acid

*also -cycloalkanes, -arenes, etc.

Table 4.1.4. Priority order of functional groups

1	carboxylic acid
2	acid anhydride
3	ester
4	acid chloride
5	amide
6	nitrile
7	aldehyde
8	ketone
9	alcohol
10	amine
11	ether
12	double bond
13	halogen

Table 4.1.5. Prefixes indicating the number of side groups of the same kind.

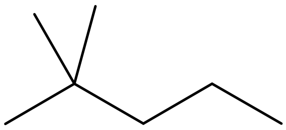
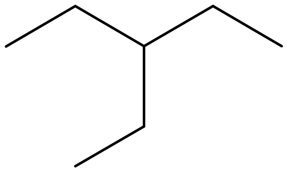
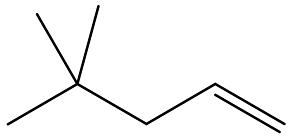
Number of groups	Prefix
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-

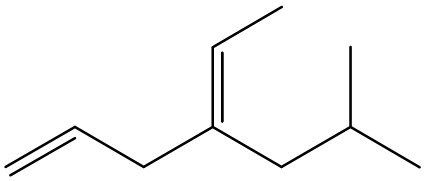
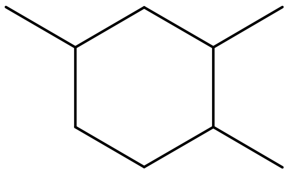
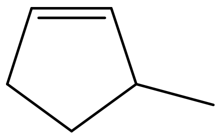
Table 4.1.6. Rules for numbering carbon atoms

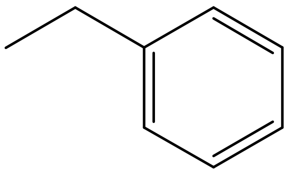
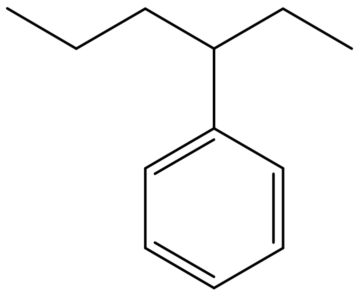
Aliphatic compounds	
1.	Choose the longest chain. If the compound contains multiple bonds, choose the longest chain containing such bonds.
2.	Identify the priority of functional groups. Number the carbon atoms in the longest chain in such a way that: a. the functional group of highest priority has the lowest possible number; b. the sum of the numbers indicating the positions of functional groups and other side groups is the lowest possible.
Alicyclic and aromatic compounds	
1.	Choose the largest ring.
2.	If there is only one functional group or side group attached to the ring, no numbering is required.
3.	For two or more functional groups or side groups: a. assign the number 1 to the carbon atom linked to the group of highest priority; b. number the other atoms in the ring in such a way that the sum of the numbers indicating the positions of the functional groups and other side groups is the lowest possible.

4.1.3. *Exercises*

1. Give the names of the following hydrocarbons

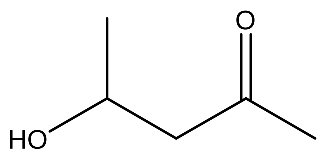




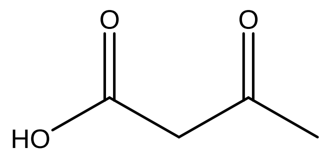



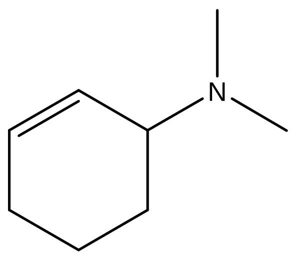
2. Draw the formulae of the following compounds:

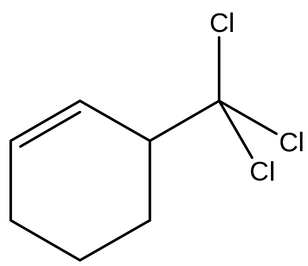
a.	4-chloropentan-2-one	
b.	cyclohexyl propanoate	
c.	3-aminobutanoic acid	
d.	1,1,3-trichlorocyclohexane	
e.	N-methyl-2-chloroethanamide	
f.	prop-2-en-1-ol	
g.	benzoic ethanoic anhydride	
h.	2-nitrobenzenesulphonic acid	
i.	N-methyl-3-ethylcyclohexylamine	
j.	2,4,6-trinitrophenol	

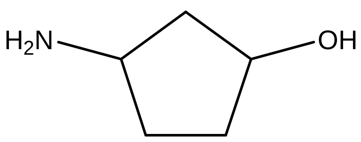
3. Give the systematic names of the following compounds:

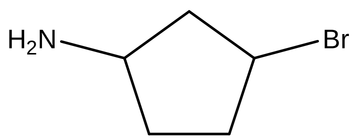




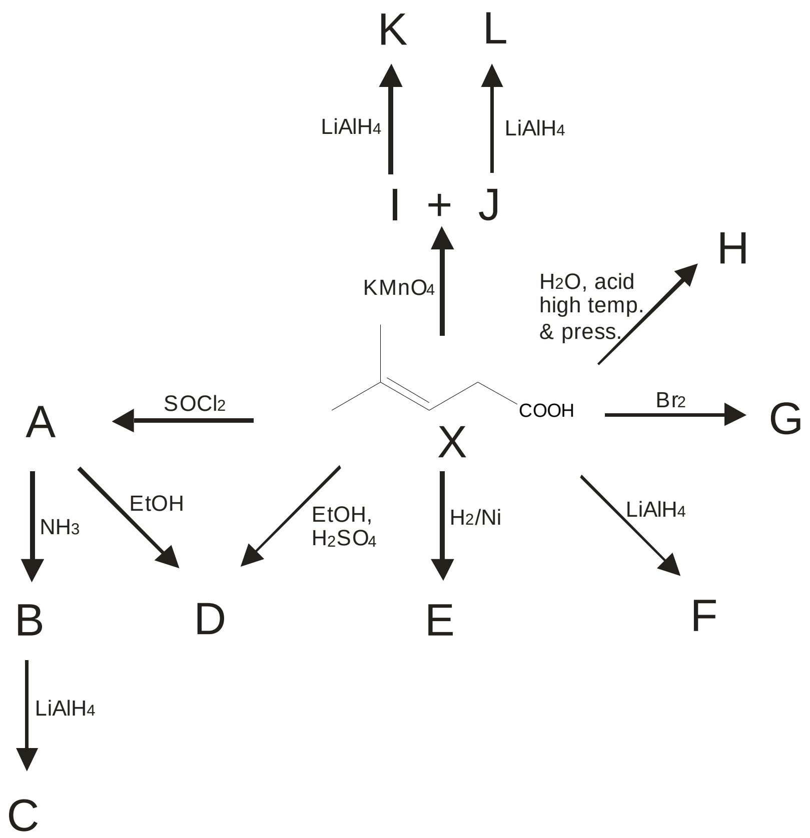








4. Name compound X, then all the reaction products A – L



X	
A	
B	
C	
D	
E	
F	
G	
H	
I	
J	
K	
L	

5. In the Chemical Laboratory

Working in the laboratory, chemists use a variety of tools, vessels and other equipment. The following synthetic procedures will make you familiar with some of them.

5.1. Cobalt(II) (cobaltous) nitrate hexahydrate $Co(NO_3)_2 \cdot 6H_2O$

(after J. Gałecki "Preparatyka nieorganiczna", WNT Warszawa, 1964)

Properties:

Red, monoclinic crystals. Density 1.883 g cm^{-3}. Melting point 55.5^oC (dissolves in its own water of crystallization). Further heating results in loss of water of crystallization and nitrogen oxides with gradual colour change from red through blue, green to black cobalt(II) oxide CoO. Solubility in water (per 100 g H_2O, anhydrous salt): 84 g at 0^oC, 161 g at 55^oC and 339 g at 91^oC. Fairly soluble in ethanol. Prepared by dissolving cobalt(III) oxide in warm nitric acid solution.

Preparation:

150 ml distilled water was measured in a measuring cylinder (graduated cylinder) and poured into a 500 ml beaker. Then 105 ml concentrated (conc.) nitric acid HNO_3 were added and the components mixed carefully with a glass rod.

The beaker was placed on a magnetic stirrer equipped with a hot plate, set up in a well-ventilated fume cupboard (fume hood). The solution was stirred and heated until the temperature reached 75^oC. Then 60 g of finely powdered cobalt(III) oxide Co_2O_3 was added in small portions using a laboratory spoon or a spatula. The mixture was stirred continuously and the temperature maintained at 75 – 85^oC.

When the addition of cobalt oxide was complete, 3 ml saturated methanal (formaldehyde) solution HCHO was added dropwise using a Pasteur pipette, to ensure that all the cobalt(III) had been reduced to cobalt(II). The mixture was stirred and heated for another 30 minutes to produce an almost clear, dark pink solution.

The stir bar was then removed from the beaker and its contents passed through a fluted paper filter placed in a glass funnel. The resulting solution (filtrate) was transferred to a large evaporating dish and the excess water was evaporated until the onset of crystallization. The mixture was cooled to 5 – 10^oC and the separated crystals removed by filtration on a sintered (fritted) glass filter. The crystals were washed with 10 ml ice-cold water, transferred to a Petri dish or large watch glass and air-dried, the temperature being gradually raised from 35 to 45°C.

The yield of pure crystalline cobalt(II) nitrate hexahydrate $Co(NO_3)_2 \cdot 6H_2O$ was 100 g (about 50%).

5.1.1. *Reading comprehension*

1. How does cobalt(II) nitrate hexahydrate behave on heating?
2. What equipment can be used for stirring mixtures?
3. What glassware would you use to measure out a specified volume of liquid?
4. How is the crystallization of the reaction product achieved?
5. What are the final steps for recovering the product?

5.1.2. *New terms and expressions*

acid dissociation constant K_a	stała kwasowa K_a
beaker	zlewka
concave	wklęsły
concentrated	stężony
cool	chłodzić
crystallization	krystalizacja
distilled water	woda destylowana
dry	suszyć
equip	wyposażyć
equipment	wyposażenie, urządzenie
evaporate	odparowywać
evaporating dish	parownica, parowniczka
fairly	dość, dosyć
filtration	sączenie
fine	drobny, silnie rozdrobniony
fluted paper filter	sączek karbowany
fold	składać, zginać
fume cupboard (fume hood)	wyciąg
funnel	lejek
glass rod	bagietka szklana

glassware	szkło laboratoryjne
handle	posługiwać się, używać
hot plate	płytka grzejna
loss	utrata
magnetic stirrer	mieszadło magnetyczne
measure	mierzyć, odmierzyć
measuring (graduated) cylinder	cylinder miarowy
mix	mieszać (ze sobą)
mixture	mieszanina
monoclinic	jednoskośny
paper filter	sączek z bibuły
pass	przepuścić
Petri dish	szalka Petriego
porcelain	porcelana
portion	porcja
powder	proszek, sproszkować
pure	czysty
raise	podnosić
reach	sięgnąć, osiągnąć
recover	wyodrębniać, odzyskiwać
remove	oddzielić, usunąć
seal	zatopić, zamknąć w osłonie
separate	wydzielić, oddzielić
set up	zmontować, ustawić
sintered (fritted) glass filter	filtr ze spieku szklanego, lejek Schotta
solubility	rozpuszczalność
spatula	łopatka
spoon	łyżeczka
stir	mieszać (przy pomocy mieszadła)
stir bar	mieszadełko (magnetyczne)
tool	narzędzie
transfer	przenieść
ventilate	wentylować
vessel	naczynie

wash	przemywać
watch glass	szkiełko zegarkowe
water of crystallization	woda krystalizacyjna
yield	wydajność

5.1.3. *Exercises*

1. Fill in the blanks in the table of physical and chemical properties of benzoic acid C_6H_5COOH:

	$C_7H_6O_2$
	122.12 g mol^{-1}
	C: 68.84%; H: 4.95%; O: 26.20%
	white crystalline solid
	1.32 g cm^{-3}`
	122^{o}C
	249^{o}C
	in water: 3.4 g dm^{-3} (25^{o}C) in benzene: 100 g dm^{-3} (25^{o}C)
	6.4×10^{-5}
	by oxidation of toluene with aq. potassium permanganate

2. Match the appropriate phrases.

cylindrical glass vessel for handling liquids	beaker
hand-held tool for stirring liquid mixtures	evaporating dish
made by the multiple folding of filter paper	glass rod
a small porcelain bowl for removing excess water from a solution	fluted paper filter
the result of chemical synthesis expressed in grams or as a percentage	watch glass
a round, slightly concave piece of glass	yield
separation of a solid compound from a saturated solution	measuring (graduated) cylinder
a small magnet sealed in heat-resistant plastic	stir bar
step by step	crystallization
used for measuring liquids	gradually

5.2. Butyl benzoate $C_6H_5COOC_4H_9$

(after A. I. Vogel "A textbook of practical organic chemistry", Longman, London 1956)

<u>Properties</u>

Colourless, oily liquid of balsamic, fruity smell. Melting point -22^oC, boiling point 249^oC, flash point 115^oC, density 1.00 g cm^{-3}. Insoluble in water, soluble in most organic solvents. It is prepared by direct esterification of benzoic acid with butanol in the presence of conc. sulphuric acid as catalyst.

Preparation

In a 500 ml round-bottomed flask place a mixture of 30 g (0.246 mol) of benzoic acid, 37 g (46 ml, 0.5 mol) of dry butanol, 50 ml of sodium-dried toluene and 10 g (5.4 ml) of conc. sulphuric acid.

Add a few boiling stones (or small chips of porous porcelain), attach a reflux condenser and boil the mixture gently for 4 hours.

Pour the reaction product into about 250 ml water contained in a separating funnel, rinsing the flask with few ml of water. Add 50 ml diethyl ether, shake the mixture in the funnel vigorously and allow to stand. Run off the lower aqueous layer, collect the upper organic layer and repeat the extraction of the water layer with another portion of ether. Wash the combined ethereal extracts with saturated sodium bicarbonate solution and then with water.

Transfer the extracts to a conical flask containing about 5 g anhydrous magnesium sulphate. Cork the flask, shake for about 5 minutes, and allow to stand for at least half an hour with occasional shaking.

Pass the solution through a fluted paper filter directly into a small round-bottomed flask. Distil off excess solvent using a rotary evaporator and a warm water bath.

Fit the flask with a two-necked adapter, a capillary ebulliator, a short fractionating column and a Liebig condenser. At the end of the condenser attach a rotating distillation receiver that allows at least two fractions to be collected in separate flasks. Distil the residue under reduced pressure, using a water aspirator pump. Collect the forerun separately, then the main fraction boiling at 119 – 120^{o}C/11 mm Hg (1.46 kPa).

The yield of pure butyl benzoate is 35 g (80%).

5.2.1. *Reading comprehension*

1. How can butyl benzoate be prepared?
2. What equipment is used for carrying out the esterification reaction?
3. How is the crude ester purified from the residual reactants – butanol, benzoic acid and sulphuric acid?

4. How are ether and toluene removed?
5. What setup is used for the final purification of the product?

5.2.2. *New terms and expressions*

adapter	nasadka
allow to stand	pozostawić (do stania)
aspirator	pompka wodna
attach	przymocować, przyłączyć
balsamic	balsamiczny
boil	gotować, utrzymywać w stanie wrzenia
boiling stone	kamyczek wrzenny
carry out	przeprowadzać
catalyst	katalizator
chip	kawałeczek, odłamek, okruch
collect	zbierać
combine	połączyć
condenser	chłodnica
conical flask	kolba stożkowa
cork	korek, zamknąć korkiem, zatkać
crude	surowy, nieoczyszczony
direct	bezpośredni
distil off	oddestylować
dry	suchy
capillary ebulliator	kapilara wrzenna
esterification	estryfikacja
extract	ekstrakt
extraction	ekstrakcja
filter	sączyć, filtrować
fit	połączyć
flame test	analiza płomieniowa
flash point	temperatura zapłonu
fluted filter paper	sączek karbowany
forerun	przedgon
fraction	frakcja

fractionating column	kolumna destylacyjna
gently	łagodnie
hygroscopic	higroskopijny
impurity	zanieczyszczenie
Liebig condenser	chłodnica Liebiga
main fraction	frakcja główna
mixture	mieszanina
mount	zestawiać, montować, mocować
occasional	od czasu do czasu
porous	porowaty
pour	wylewać, przelewać, nalewać
reactant	substrat
reduced pressure	zmniejszone ciśnienie
reflux	ogrzewać tak, aby pary się skraplały i powracały do roztworu (pod chłodnicą zwrotną)
reflux condenser	chłodnica zwrotna
residue	pozostałość
rinse	opłukiwać
rotary evaporator	wyparka próżniowa, rotawapor
rotating distillation receiver	świnka (krówka) obrotowa
round-bottomed flask	kolba okrągłodenna
rubber	guma, gumowy
run off	spuścić (ciecz ze zbiornika)
saturated	nasycony
sensitive	wrażliwy
separating funnel	rozdzielacz
setup	zestaw
shake	wytrząsać
sodium-dried	wysuszony nad sodem
solvent	rozpuszczalnik
text-book, textbook	podręcznik
two-necked adapter	nasadka dwuszyjna
water bath	łaźnia wodna

5.2.3. *Exercises*

1. Which of the following statements concerning the preparation of butyl benzoate are true (T) and which are false (F).

a.	Sulphuric acid is used as a catalyst in the esterification of benzoic acid with butanol.	T / F
b.	This reaction is not sensitive to the presence of water.	T / F
c.	Boiling stones are used to ensure the smooth, gentle boiling of the reaction mixture.	T / F
d.	When an aqueous solution is extracted with ether, the reaction product is contained in the lower layer in the separating funnel.	T / F
e.	Washing ether extracts with sodium bicarbonate solution removes residual butanol from the product.	T / F
f.	Toluene is removed from the product at a temperature far below its boiling point at normal pressure.	T / F
g.	The final purification step involves crystallization of the product.	T / F

2. Examine **Table 5.2.1.** Give the names of at least three different pieces of apparatus used in the following operations:

running a reaction at the temperature of the boiling solvent	
separation of the solid reaction product from the solution	
separation of solid impurities from the solution of the reaction product	
distillation	
purification of a gas	
measuring the pH of a solution	
doing a flame test	
removing traces of water from a hygroscopic solid	
extraction of the reaction product from aqueous solution	
assembling a vacuum distillation setup	

3. Examine **Table 5.2.1.** Match the pieces of laboratory apparatus with the materials they are made from.

	conical flask
glass	
	stopper
	hose
porcelain	
	bulb
	glove box
metal	
	Büchner funnel
	spoon
plastic	
	crucible
	burette
rubber	
	thermometer
	Bunsen burner
cork	
	filter
	tongs
paper	
	separating funnel

Table 5.2.1. The glassware and apparatus most often used in the chemical laboratory

1. Reaction vessels and containers	**1. Naczynia reakcyjne**
beaker	zlewka
round-bottomed flask	kolba okrągłodenna
three-necked round-bottomed flask	kolba trójszyjna
conical flask, Erlenmeyer flask	kolba stożkowa, erlenmajerka
Dewar flask	naczynie Dewara, termos
test tube	probówka
crucible	tygiel
evaporating dish	parownica, parowniczka
2. Storage containers	**2. Naczynia do przechowywania**
bottle	butla, butelka
jar	słój
watch glass	szkiełko zegarkowe
Petri dish	szalka Petriego
vial	fiolka
ampoule	ampułka
dessicator	eksykator
3. Solid handling & measurement	**3. Praca z substancjami stałymi**
spatula	łopatka
spoon	łyżeczka
glass rod	bagietka
pestle & mortar	tłuczek i moździeż
weighing bottle	naczynko wagowe
weighing tray	tacka do ważenia
weighing paper	papier do ważenia

4. Liquid handling & measurement	**4. Praca z cieczami**
funnel	lejek
Pasteur pipette	pipeta Pasteura
dropper	kroplomierz, zakraplacz
measuring (graduated) cylinder	cylinder miarowy
volumetric flask	kolba miarowa
pipette	pipeta
graduated pipette	pipeta z podziałką
burette	biureta
stopcock	kranik, kurek
dropping funnel	wkraplacz
syringe	strzykawka
rubber bulb	gruszka gumowa
5. Gas handling & measurement	**5. Praca z gazami**
gas cylinder	butla z gazem (metalowa)
gas bubbler	bełkotka
washing bottle, scrubber	płuczka do gazu
valve (two-way ..., three-way ...)	zawór (dwudrożny, trójdrożny)
drying tube	rurka ze środkiem suszącym
absorber	absorber, kolumna absorpcyjna
6. Vapour/liquid handling	**6. Praca z cieczą i parą**
boiling flask	kolba reakcyjna, destylacyjna
boiling stone	kamyczek wrzenny
distillation adapter	nasadka destylacyjna
thermometer	termometr
condenser	chłodnica
reflux condenser	chłodnica zwrotna
Liebig condenser	chłodnica Liebiga
fractionating column (e.g. Vigreux)	kolumna destylacyjna (np. Vigreux)
receiver, receiving flask	odbieralnik
Schlenk line	aparatura Schlenka

7. Vacuum glassware	**7. Aparatura próżniowa**
aspirator	pompka wodna
Büchner flask	kolba ssawkowa
tubing	przewody elastyczne (węże)
hose connection	króciec do przyłączania węży
distillation capillary, ebulliator	kapilara wrzenna
rotating distillation receiver	świnka, krówka
manometer	manometr
8. Separation techniques	**8. Techniki rozdziału**
Büchner funnel	lejek Buchnera
paper filter	sączek bibułowy (papierowy)
filter paper	bibuła filtracyjna
fluted paper filter	sączek karbowany
sintered (fritted) glass filters	filtr ze spiekanego szkła, lejek Schotta
separating funnel	rozdzielacz
chromatography column	kolumna chromatograficzna
chromatography paper	bibuła chromatograficzna
chromatography plate, TLC plate	płytka chromatograficzna
Soxhlet extractor	aparat Soxhleta
indicator paper	papierek wskaźnikowy
9. Stoppers	**9. Zamknięcia**
glass stopper	korek szklany
rubber bung	korek gumowy
cork stopper	korek z korka
screw cap	zakrętka

10. Joints	**10. Złącza**
ground glass joint (conically tapered)	szlif stożkowy
ball and socket joint	szlif kulisty
Keck clip	klamra do zabezpieczania połączeń
O-ring joint	złącze typu O-ring
O-ring seal	uszczelka typu O-ring
expansion adapter	reduktor (z mniejszego na większy)
reduction adapter	reduktor (z większego na mniejszy)
11. Metal labware	**11. Sprzęt metalowy**
laboratory stand	statyw
clamp	łapa
support ring	kółko (podtrzymujące)
clamp holder	łącznik do łap
tripod	trójnóg
Bunsen burner	palnik Bunsena
wire gauze	siatka azbestowa
tongs	szczypce
12. Laboratory equipment	**12. Urządzenia laboratoryjne**
hot plate	płytka grzejna
heating mantle	czasza grzejna
stirrer	mieszadło
magnetic stirrer	mieszadło magnetyczne
stir bar (flea)	mieszadełko magnetyczne (kaczka)
fume hood	wyciąg
analytical balance	waga analityczna
glove box	komora rękawicowa
glove bag	nadmuchiwana komora rękawicowa
oven	piec, suszarka
dryer, blow dryer	suszarka (dmuchająca powietrzem)
vacuum pump	pompa próżniowa
centrifuge	wirówka
water bath	łaźnia wodna

oil bath	łaźnia olejowa
thermostatic bath	termostat
rotary evaporator, rotavapor	wyparka próżniowa, rotawapor
pH-meter	pehametr
glass electrode	elektroda szklana

6. Chemical Analysis

6.1. Analytical tests (qualitative analysis)

Chemists use analytical tests to identify inorganic and organic compounds. An analytical test is a specific chemical reaction whose result confirms or discounts the presence of a particular compound, ion or functional group.

Some metal ions can be detected by a simple flame test. When a small portion of a fairly volatile metal salt (such as a chloride) is placed in a Bunsen burner flame, the colour of the flame gives clues to the identity of the metal ion. For example, a yellow flame indicates the presence of sodium ions, brick-red – calcium ions, green – barium or copper ions.

Many ions can be identified in solution by reaction with appropriate reagents and by observing their effects.

Analytical tests for iron(III) ion:

The addition of sodium hydroxide or ammonia to a solution of iron(III) salt produces a red-brown, gelatinous precipitate of iron(III) hydroxide $Fe(OH)_3$, which is insoluble in excess of the reagent. The presence of Fe^{3+} can also be detected by the formation of intensely coloured compounds: reaction with the thiocyanate ion SCN^- produces red-brown thiocyanato complex ions, while the reaction with the hexacyanoferrate(II) ion $[Fe(SCN)_6]^{4-}$ gives a colloidal, dark-blue precipitate of Prussian blue.

Analytical tests are also used in organic chemistry. The discolouration of bromine water is a common test for detecting double bonds. Acidity/basicity tests are used for identifying carboxylic acids or amines. Brady's test indicates the presence of a carbonyl group when the formation of yellow-orange 2,4-dinitrophenylhydrazone is observed, while the following Lucas test allows one to tell aldehydes from ketones.

Lucas test:

The Lucas test is used to distinguish among primary, secondary and tertiary alcohols. In a typical experiment, some of the alcohol is added to a solution of zinc chloride in hydrochloric acid, after which the mixture is shaken. Tertiary alcohols readily form the corresponding alkyl chlorides. Since these compounds are insoluble in water, the mixture turns cloudy almost instantaneously, and soon two liquid layers separate. With secondary alcohols the reaction is slower, so the turbidity appears only after several minutes. Primary alcohols practically do not react with hydrochloric acid under these conditions, so the solution remains transparent.

6.1.1. *Reading comprehension*

1. What is the easiest way of detecting sodium ions?
2. How can we distinguish between calcium and barium ions using a flame test?
3. How do iron(III) ions react with ammonia?
4. What tests are used for the detection of carboxylic acids and aldehydes?
5. What is the difference between the reaction of primary and tertiary alcohols using the Lucas test?
6. How would you account for this difference?
7. Why does a turbid solution indicate a positive result of the Lucas test?

6.1.2. *New terms and expressions*

analytical test	test analityczny, próba
brick	cegła
bromine water	woda bromowa
cloudy	nieprzeźroczysty, mętny
clue	wskazówka, sugestia, informacja
colloidal	koloidalny
confirm	potwierdzać
deposit	osadzić (się)
discolouration	odbarwienie
discount	odrzucić
distinguish	odróżnić
fair	przyzwoity, umiarkowany
flame test	analiza płomieniowa
gelatinous	galaretowaty
identification	wykrywanie
identity	tożsamość
instantaneous	natychmiastowy
intense	intensywny
primary, 1^{o}	pierwszorzędowy

Prussian blue	błękit pruski
pungent	ostry, gryzący, drażniący
qualitative	jakościowy
secondary, 2^o	drugorzędowy
tell ... from ...	odróżnić
tertiary, 3^o	trzeciorzędowy
transparent	przeźroczysty
turbidity	zmętnienie
volatile	lotny

6.1.3. *Exercises*

1. Give examples of analytical tests for:

a. the copper(II) ion

....

....

....

....

....

b. the chloride ion

....

....

....

....

....

c. reducing monosaccharides (e.g. glucose)

....

....

....

....

....

d. carboxylic acids

....

....

....

....

....

2. Fill in the blanks in the following paragraphs.

a. A solution containing cations of A is dark blue. The addition of NaOH solution produces a grey .... that dissolves in an .... of the reagent to give a deep green solution. The addition of hydrogen peroxide results in the formation of the yellow .... product B. When the solution of B is .... with sulphuric acid, the colour changes to .... , which indicates that B ions have been converted to C. The test indicates that A is a .... ion, B a .... ion and C a .... ion.

b. The addition of some sulphuric acid and then potassium dichromate to alcohol D results in a colour change from .... to green. Distillation of the resulting mixture produces some volatile liquid E with a distinctive, pungent .... If a few drops of E are added to a solution of .... reagent and the test tube is placed for a while in a warm .... , a silver .... is deposited on the walls of the tube. The reaction of E with a dark .... , alkaline solution of copper(II) ions yields a .... precipitate of .... …………... . The test indicates that D is a .... alcohol and that E belongs to the family of ....

6.2. Titration (an example of quantitative analysis)

Titration is an analytical technique still in common use in chemical laboratories today. It is a kind of volumetric analysis, involving the measurement of the volume of reactant A solution required to react quantitatively with an unknown amount of reactant B, which is determined in the experiment.

The typical titration setup consists of a burette mounted on a laboratory stand and a conical flask. The solution of analyte of unknown concentration is placed in the flask, then a few drops of indicator solution are added. The burette is filled with a standardized titrant solution of precisely known molarity. The level of the solution is carefully adjusted to read zero.

The titrant is then added stepwise to the analyte solution. After each portion, the contents of the flask are swirled to ensure the even distribution of titrant throughout the solution. The titrant continues to be added – dropwise, when the endpoint is thought to be approaching – until the next drop of titrant permanently changes the colour of the indicator.

Acid-base titration involves a neutralization reaction between acids and bases. The stepwise addition of base to acid results in a gradual change in the pH of the solution, represented graphically by the pH curve. At the beginning of the titration, the pH of the solution changes quite slowly, but near the endpoint (equivalence point) we observe a dramatic, almost vertical rise of the curve. The most common indicators used in acid-base titrations are phenolphthalein and methyl orange. The course of titration can also be monitored with a pH-meter, whose glass electrode is sensitive to the concentration of hydrogen ions.

Other types of reactions are used in titration as well: reduction-oxidation reaction (redox titration), complex ion formation (complexometric titration) or the precipitation of an insoluble product (precipitometry).

Table 6.2.1. Types of titration

Type	Analyte	Titrant	Indicator
Acidimetric (acid-base)	acids, bases	sodium hydroxide hydrochloric acid	phenolphthalein methyl orange bromothymol blue
Redox			
manganometric	reductants, e.g. iron(II), hydrogen peroxide, oxalates	potassium permanganate	none
iodometric	oxidants, e.g. iron(III), copper(II),	sodium thiosulphate	starch
Complexometric	metal ions	EDTA	eriochrome black T murexide
Precipitometric			
argentometric	halide ions	silver nitrate	potassium dichromate

6.2.1. *Reading comprehension*

1. What is titration?
2. What is the difference between volumetric and gravimetric analysis?
3. How would you assemble a simple titration setup?
4. What are the methods for determining the endpoint?
5. What types of reaction are used in titration?
6. What is the shape of a typical titration curve?
7. Do all titration types require the use of an indicator?

6.2.2. *New terms and expressions*

acid-base titration	miareczkowanie kwasowo-zasadowe
acidimetric	acydymetryczny
adjust	skorygować, dopasować
analyte	substancja oznaczana, analit
argentometric	argentometryczny
bromothymol blue	błękit bromotymolowy
complexometric	kompleksometryczny

concentration	stężenie
course	przebieg
determine	oznaczać
dramatic	gwałtowny
drop	kropla
dropwise	(kropla) po kropli
EDTA	EDTA, wersenian
endpoint	punkt końcowy
equivalence point	punkt równoważnikowy
eriochrome black T	czerń eriochromowa T
even	równomierny
fill	napełniać
gravimetric analysis	analiza wagowa
hydrogen peroxide	nadtlenek wodoru
indicator	wskaźnik
iodometric	jodometryczny
manganometric	manganometryczny
methyl orange	oranż metylowy
molarity	stężenie molowe
monitor	śledzić, monitorować, obserwować
murexide	mureksyd
oxalate	szczawian
oxidant (oxidizing agent)	utleniacz
oxidation	utlenianie
permanent	trwały
pH curve	krzywa pH
phenolphthalein	fenoloftaleina
precipitometric	precypitometryczny
precise	precyzyjny, dokładny
quantitative	ilościowy
reductant (reducing agent)	reduktor
reduction	redukcja
sodium thiosulphate	tiosiarczan sodu
stepwise	krok po kroku, stopniowy

swirl	zamieszać (ruchem okrężnym)
technique	technika
titration	miareczkowanie
volume	objętość
volumetric analysis	analiza objętościowa

6.2.3. *Exercises*

1. Give the words or phrases that correspond with the following descriptions.

A graduated glass tube equipped with a stopcock.	
You do this after the addition of each portion of titrant.	
A compound that changes colour when the pH turns from acidic to alkaline.	
An organic compound that is colourless in acidic solution but pink in alkaline solution.	
A substance of unknown concentration that is being determined by titration	
A type of titration involving the precipitation of an insoluble reaction product.	
A class of compounds that can be determined by iodometric titration.	
The point at which the whole quantity of the compound to be determined has reacted completely with the titrant.	
A solution of precisely known molarity.	
A type of analysis that determines the identity of an unknown compound.	
A type of analysis that determines the amount of an unknown compound.	

2. Fill in the blanks in the following paragraph.

A 10 ml portion of 1 M sodium iodide was .... to a solution of iron(III) ions of unknown .... The solution turned dark ...., since iodide ions were .... to .... Then a few drops of .... solution was added as indicator and the mixture was .... against .... sodium .... solution, until the .... colour disappeared. Since the .... and .... of the titrant were known, the unknown amount of .... could be determined readily. The procedure described above is an example of .... titration.

7. Chromatography

7.1. Principles of chromatography

Chromatography was discovered by the Russian botanist Mikhail Tsvet (Михаил Цвет) in 1900, when he tried to separate plant pigments by passing a leaf extract through a glass tube packed with finely powdered calcium carbonate. He found out that natural chlorophyll is actually a mixture of several different compounds. Today, chromatography is one of the most widespread laboratory techniques used for the analytical or preparative separation of mixtures.

In principle, chromatography involves passing a mixture of components, contained in a mobile phase (gaseous or liquid), through a stationary phase (liquid or solid), fixed to some kind of support, such as a glass plate or column. Different molecules carried by the mobile phase are attracted to the stationary phase to a different degree. Those interfering only weakly migrate quickly through the stationary phase and come out first. Those that are attracted more strongly migrate at a slower rate, so they are retained longer. As a result, the components are separated.

7.1.1. *Reading comprehension*

1. How was chromatography discovered?
2. What is chromatography about?
3. How does the chromatographic separation of components occur?

7.1.2. *New terms and expressions*

botanist	botanik
carry	nieść
chlorophyll	chlorofil
chromatography	chromatografia
discover	odkryć
find out	odkryć, dowiedzieć się
interfere	oddziaływać
leaf (leaves)	liść (liście)
migrate	przemieszczać się, wędrować

mobile phase	faza ruchoma
pack	wypełniać
pass	przepuszczać, przechodzić
preparative	preparatywny
retain	zatrzymywać
separate	rozdzielać
stationary phase	faza nieruchoma, stacjonarna
support	podłoże
widespread	szeroko rozpowszechniony

7.1.3. *Exercise*

The process of chromatographic separation may be compared to the situation when a swarm of bees and wasps flies over a bed of flowers. Bees, which are honey gatherers, are more attracted to flowers than wasps, which are generally carnivorous. Every now and then, bees will alight on a flower, sip some nectar, and take off again. Wasps take much less interest in flowers, so they will fly straight ahead. Thus, the wasps reach the end of the flower bed first, while the bees arrive at the same place much later. As a result, the wasps are separated from the bees.

Use 'chromatographic' terminology to describe this process of separation:

wasps and bees	
wasps	
bees	
air	
flower bed	
smell of flowers	
effective speed of flying insect	

Vocabulary for the exercise:

ahead	naprzód
alight	siadać, lądować
bee	pszczoła
carnivorous	mięsożerny
flight	lot
flower bed	klomb kwiatów, rabata
gatherer	zbieracz
honey	miód
insect	owad
nectar	nektar
sip	łyknąć, pociągnąć, siorbnąć
swarm	rój
take off	startować, oderwać się od ziemi, pofrunąć
wasp	osa

7.2. Chromatography in the laboratory

Paper chromatography uses a strip of paper as the stationary phase. The mobile phase is an organic solvent (or a mixture of solvents) immiscible in water. A drop of sample solution is placed near the end of the strip, which is then dipped in the solvent. As the solvent passes through paper, the constituents of the sample dissolve in the water adsorbed on the cellulose fibres, after which they are extracted back into the solvent. The rate of migration of a particular compound depends on the partition coefficient, that is, on the ratio of its concentrations in water and the organic solvent. Less polar compounds, better soluble in the organic phase, tend to travel with the solvent front. More polar ones have longer retention times (lower values of the retention factor R_f).

The resulting chromatogram usually needs to be developed to visualize the spots corresponding to different compounds. For example, ninhydrin is commonly used for developing chromatograms of amino acids and peptides.

In thin layer chromatography (TLC), the stationary phase is a layer of finely powdered adsorbent, such as silica or alumina gel, spread over a flat surface – a glass plate, aluminium foil or plastic sheet. Again, the polarity of the compound determines its rate of migration through the stationary phase. Highly polar compounds are strongly adsorbed to the surface of silica gel, which is covered with polar hydroxyl groups, whereas non-polar compounds interact only weakly with this adsorbent.

For preparative purposes, column chromatography is used. The adsorbent is packed in long glass columns and the mixture of compounds is placed at the top of the column. As solvent passes through the adsorbent, the components are separated and eluted one by one in separate fractions.

7.2.1. *Reading comprehension*

1. What are the stationary and mobile phases in paper chromatography?
2. Which parameter determines the migration rate of a particular compound through paper?
3. What does the symbol R_f stand for?
4. How can one visualize the spots of different compounds on a chromatogram?
5. What adsorbents are used in TLC?
6. Which compound would you expect to have higher a R_f value in TLC on silica: ethanol or chloroethane?
7. What equipment is used for preparative chromatography?

7.2.2. *New terms and expressions*

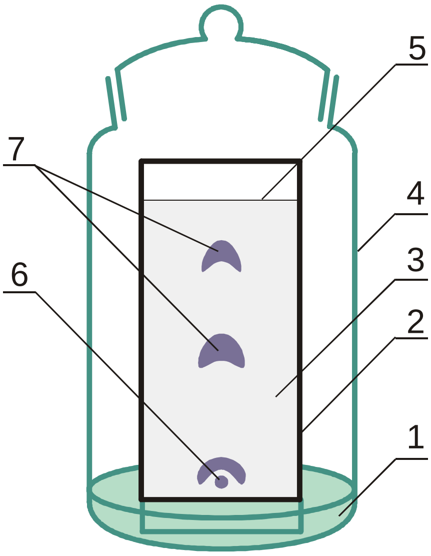
adsorb	zaadsorbować
adsorbent	adsorbent
alumina	tlenek glinu
amino acid	aminokwas
chromatogram	chromatogram
column chromatography	chromatografia kolumnowa
develop	rozwijać, wywołać
dip	zanurzyć, zamoczyć
elute	wymywać

fibre (US fiber)	włókno
immiscible	nie mieszający się
ninhydrin	ninhydryna
pack	napełnić (czymś sypkim, stałym)
paper chromatography	chromatografia bibułowa
partition coefficient	współczynnik podziału
peptide	peptyd
plate	płytka
preparative	preparatywny
retention factor	współczynnik retencji R_f
retention time	czas retencji
sheet	arkusz
silica	krzemionka
silica gel	żel krzemionkowy
solvent front	czoło rozpuszczalnika
spot	plamka, miejsce
spread	rozsmarować, pokryć coś
surface	powierzchnia
thin layer chromatography	chromatografia cienkowarstwowa
visualize	uwidocznić

7.2.3. *Exercises*

1. Label all the parts in the diagram of paper chromatography.

1	
2	
3	
4	
5	
6	
7	



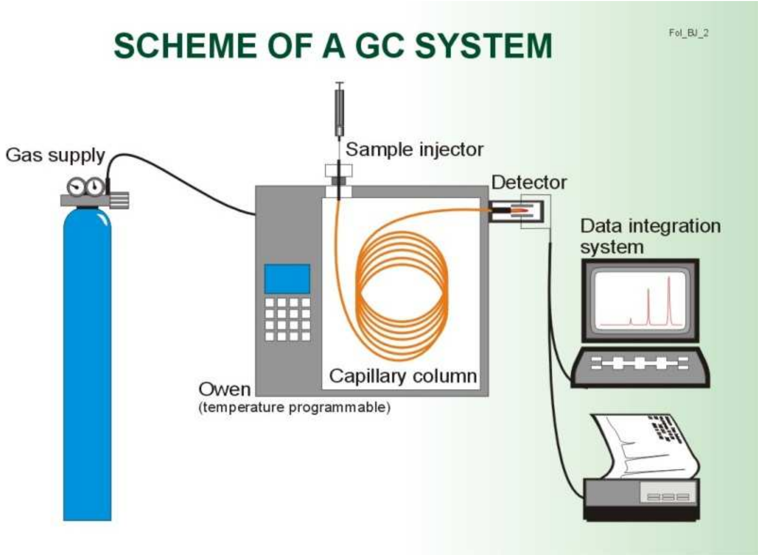
2. Fill in the blanks.

To assess the progress of the reaction in which benzoic acid was reduced to benzyl alcohol, a tiny .... of reaction mixture was placed near one end of a glass .... covered with .... gel. The plate was then .... in a methanol-chloroform mixture. When the .... had almost reached the top, the plate was removed, ...- .... and placed in a jar with a few crystals of .... at the bottom. The .... were visualized as dark-brown spots. Since the lower spot was much more intense than the upper one, the reduction was ....

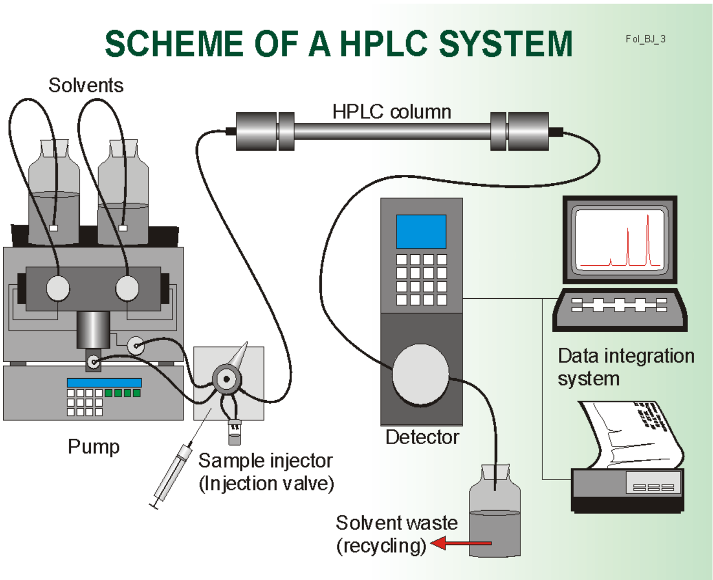
7.3. Instrumental laboratory techniques

Chromatography is used in instrumental methods as well. The two most important ones are gas chromatography (GC) and high performance liquid chromatography (HPLC).

In GC, the mobile phase is an inert gas, such as nitrogen, argon or helium. Solid porous adsorbents or high-boiling liquids placed on a porous material are used as stationary phases. In capillary GC, the liquid stationary phase covers the inner walls of a very long, narrow, spirally twisted column. Usually, gas chromatographs operate at high temperature to ensure the appropriate volatility of the analytes. The result of the analysis takes the form of a chromatogram, recorded by a detector and processed using a data integration system. A typical chromatogram consists of a number of peaks, each corresponding to a different component in the sample analysed.



HPLC uses liquid solvents as mobile phase. The solvent, or mixture of solvents, is forced at very high pressure through columns filled with the stationary phase. There are two general types of HPLC analysis: normal-phase separation and reversed-phase separation. The former uses a polar column packing, such as silica gel and non-polar solvents (hexane, dichloromethane, etc.). Reversed-phase separation is far more common. It uses a non-polar column packing and polar solvents (e.g. methanol/water or acetonitrile/water buffer solution). Reversed-phase adsorbents are manufactured by the chemical modification of silica: alkyl fragments are attached to the hydroxyl groups at the surface. In this case, the more polar compounds migrate through the column faster than the less polar ones do.



7.3.1. *Reading comprehension*

1. What is the mobile phase in gas chromatography?
2. How is a stationary phase prepared in GC?
3. Why are GC experiments usually carried out at elevated temperature?
4. What does a typical GC chromatogram look like?
5. What is the mobile phase in HPLC?
6. How would you explain the idea of reversed-phase chromatography?

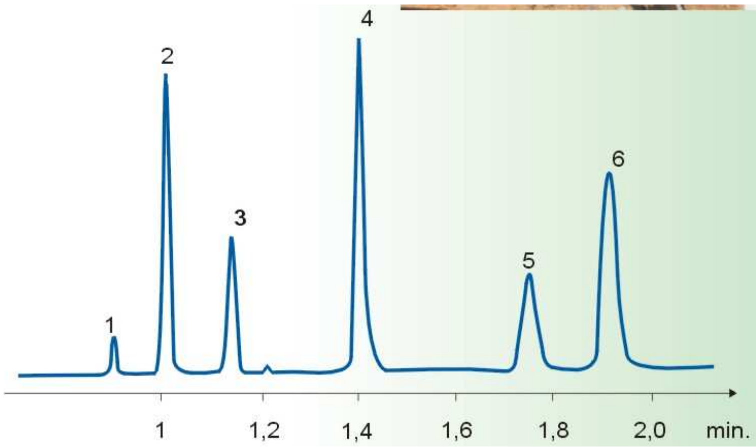
7.3.2. *New terms and expressions*

assess	ocenić, oszacować
beverage	napój
capillary	kapilara
carrier	nośnik
congener	kongener, związek zawierający tę samą grupę funkcyjną lecz różną liczbę atomów węgla
data integration system	integrator
force	wtłaczać, wpychać
gas chromatography	chromatografia gazowa
high performance liquid chromatography	wysokorozdzielcza chromatografia cieczowa
homologous series	szereg homologiczny
inert	obojętny
instrumental method	metoda instrumentalna
isothermal	izotermiczny
metabolite	metabolit
narrow	wąski
packing	wypełnienie
peak	pik
pressure	ciśnienie
reversed-phase	faza odwrócona
spiral	spiralny, spirala
twist	skręcać

7.3.3. *Exercise*

The GC chromatogram of a sample of blood taken from a drunken driver is shown below. Apart from ethanol, a number of other volatile compounds are detected. They are congeners of ethanol (alcohols having more or fewer carbon atoms in the molecule) as well as metabolites (which in the case of alcohols are oxidation products). Try to identify all the peaks.

Column:	RTX BAC 2
Carrier:	helium
Oven:	40^{o}C (isothermal)
Injection:	1 ml
Detector:	FID, 200^{o}C



Peak	Compound description	Compound name
1	alcohol congener	
2	oxidation product, reacts with Tollens reagent	
3	main component of alcoholic beverages	
4	oxidation product, does not react with Tollens reagent	
5	alcohol congener	
6	alcohol congener, the same number of C atoms as in 5	

Notes:

a. In a homologous series, the more carbon atoms in the molecule, the higher the boiling point.

b. Branched isomers have always lower boiling points than linear ones.

c. Hydrogen bonding is at least 10 times stronger than electrostatic dipole-dipole interaction.

8. Bibliography

1. R. Chang "Chemistry", McGraw Hill, 2002, Boston, USA.
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3. T. W. G. Solomons, C. G. Fryhle "Organic Chemistry", John Wiley & Sons, Inc., 2002, New York, USA.