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JĘZYK ANGIELSKI W CHEMII I W OCHRONIE ŚRODOWISKA

Wydawnictwo Uniwersytetu Gdańskiego

Marek Kwiatkowski
Piotr Stepnowski

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Uniwersytet Gdański
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Skład komputerowy: Marek Kwiatkowski

Redakcja naukowa: Marek Kwiatkowski

Korekta językowa: Peter Senn

Recenzent: prof. dr hab. inż. Waldemar Wardencki

Okładkę i strony tytułowe zaprojektowali: Anna Białk-Bielińska, Jolanta Kumirska, Marek Kwiatkowski

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Uniwersytet Gdański
Wydział Chemii
80-952 Gdańsk, ul. Sobieskiego 18

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WSTĘP

Kształcenie umiejętności posługiwania się specjalistycznym językiem angielskim, specyficznym dla nauk chemicznych oraz nauk związanych z szeroko pojętą ochroną środowiska, jest ważnym elementem studiów na Wydziale Chemii Uniwersytetu Gdańskiego. Skrypt *Język angielski w chemii i ochronie środowiska* powstał w celu wspierania realizowanego od kilku lat przedmiotu "Nomenklatura chemiczna w języku angielskim" dla studentów III roku studiów I stopnia na kierunku CHEMIA oraz planowanego przedmiotu fakultatywnego o podobnym charakterze dla studentów studiów I stopnia na kierunku OCHRONA ŚRODOWISKA.

Fragment podręcznika skierowany do studentów chemii składa się z 15 rozdziałów, przeznaczonych do realizacji w cyklu cotygodniowych dwugodzinnych spotkań w przeciągu semestru studiów. Część przeznaczona dla studentów ochrony środowiska zawiera 4 obszerniejsze rozdziały przeznaczone do realizacji w ciągu czterech trzygodzinnych spotkań.

Każdy z rozdziałów posiada jednolitą strukturę, na którą składają się: teksty wprowadzające nowe słownictwo, pytania sprawdzające zrozumienie tekstu, słowniczki nowych pojęć oraz ćwiczenia do wykonania przez studentów. Teksty mają charakter syntetycznej informacji na tematy znane już studentom z wcześniejszych lat studiów, podanej w języku angielskim. Ćwiczenia zostały zaprojektowane w taki sposób, aby można było je wykonywać przy pomocy tablicy interaktywnej, co w znaczący sposób zwiększa aktywność i zaangażowanie słuchaczy w proces dydaktyczny. W skrypcie zachowano pisownię typową dla klasycznej, brytyjskiej wersji języka angielskiego.

Autorzy mają nadzieję, że skrypt *Język angielski w chemii i ochronie środowiska* stanie się ważną pozycją wspomagającą kształcenie studentów na Wydziale Chemii Uniwersytetu Gdańskiego.

Gdańsk, 30 września 2010 r.
Marek Kwiatkowski
Piotr Stepnowski

1. Mathematics in Chemistry

1.1. Mathematics in chemistry

Chemistry is the study of matter and the changes it undergoes. Chemistry is governed by certain laws. A number of them take the form of mathematical expressions. Mathematics is important for the proper understanding of many chemical relationships. Therefore, we will first learn the mathematical terminology.

There are four basic operations on numbers: addition, subtraction, multiplication and division.

Operation	Action	Result	Numerical expression	Verbal expression
addition	to add to	sum	$2 + 2 = 4$	two plus two equals (is, is equal to) four
subtraction	to subtract from	difference	$5 – 3 = 2$	five minus three equals (...) two
multiplication	to multiply by	product	$6 \times 7 = 42$	six times seven equals (...) forty two
division	to divide by	quotient (ratio)	$4 \div 5 = 4/5 = \frac{4}{5} = 0.8$	four divided by five (four over five) equals (...) four fifths, zero (oh, nought) point eight.

The division of two integers often produces a fraction. The upper figure in the fraction is called the numerator and the lower one is the denominator. The same applies to mathematical expressions. For example, in $\frac{2a+b}{4c}$, '$2a + b$' is the numerator and '$4c$' is the denominator.

In the expression 2^3, the integer two is raised to the power of three. The superscript is called the exponent. Exponents are used in scientific notation; this is a common way of expressing very large and very small numbers in chemistry, for example:

Floating point notation		Scientific notation	
numerical	verbal	numerical	verbal
6 870 000	six million eight hundred and seventy thousand	6.87×10^6	six point eight seven times ten to the power six / ten to the sixth
0.000018	zero point zero zero zero zero one eight (or oh, nought instead of zero)	1.8×10^{-5}	one point eight times ten to the power minus five / ten to the minus five

Exponents 2 and 3 have special names: 4^2 is spoken 'four squared' and 5^3 is 'five cubed'.

The other way of expressing very large or very small numbers is to use logarithms. Chemists often use common logarithms (or base 10 logarithms) to give the values of equilibrium constants, rate constants or pH. The expression $\log 2 = 0.3$ reads 'the logarithm of two equals zero (oh, nought) point three'.

Many chemical and physical values are expressed in specific units. Examples of such units are kg (kilogram), m^2 (square metre), g cm^{-3} (gram per cubic centimetre).

1.1.1. *Reading comprehension:*

1. What are the four basic mathematical operations?
2. Do we always obtain an integer when we divide two integers?
3. When do we use scientific notation?
4. How do chemists often express the values of chemical constants?
5. What units do we use to express the speed of a car?

1.1.2. *New terms and expressions:*

addition	dodawanie
constant	stała
cube	sześcian
denominator	mianownik

difference	różnica
division	dzielenie
equilibrium	równowaga
exponent	wykładnik
expression	wyrażenie (wzór matematyczny)
fraction	ułamek
integer	liczba całkowita
law	prawo
logarithm	logarytm
mathematics	matematyka
matter	materia
multiplication	mnożenie
numerator	licznik
power	potęga
product	iloczyn
quotient	iloraz
rate	szybkość (reakcji)
ratio	stosunek (iloraz)
relationship	zależność
square	kwadrat
subtraction	odejmowanie
sum	suma
unit	jednostka

1.1.3. *Exercises*

1. Read the following expressions aloud:

   a. log1000 = 3
   b. 0.03 + 0.07 = 0.1
   c. 2000 – 1 = 1999
   d. $7^2 = 7 \times 7 = 49$
   e. $3 \div 500 = 0.006 = 6\times10^{-3}$
   f. $\log(1.8\times10^{-5}) = \log(10^{-4.74}) = -4.74$
   g. 12.27 mg
   h. 0.05 mol dm^{-3}
   i. 727 kJ mol^{-1}

2. Match the mathematical expressions (printed in bold) with their descriptions:

$\mathbf{3 + 3} = 6$

$7 - 2 = \mathbf{5}$

$\mathbf{2 \times 7} = 14$

$32 \div 4 = \mathbf{8}$

$5^{\mathbf{4}}$

$\mathbf{3^2}$

$\mathbf{log}(2.7)$

$\mathbf{\frac{4}{5}}$

$\frac{3}{\mathbf{8}}$

the cube of ...
the logarithm of ...
the square of ...
addition
a unit of ...
denominator
difference
division
exponent
fraction
integer
multiplication
numerator
power
product
quotient
subtraction
sum

1.2. Other mathematical expressions useful for chemists:

1.2.1. *Roots*

root	pierwiastek
square root	pierwiastek kwadratowy
cube root	pierwiastek sześcienny
n-th root	pierwiastek *n*-tego stopnia

Usage: The square root of four is two. Take the cube root of 27 and divide it by three.

1.2.2. *Equations*

equation	równanie
linear equation	równanie pierwszego stopnia
quadratic equation	równanie drugiego stopnia
solution	rozwiązanie

1.2.3. *Exercise*

1. Give the names of the following mathematical expressions:

a. $2x + 2 = 8$; $x = 3$ ....; ....

b. $3x^2 + 2x - 2 = 0$ ....

c. $\sqrt{7}$ ....

d. 2^{16} ....

1.2.4. *Differential calculus*

differential calculus	rachunek różniczkowy
differentiation	różniczkowanie
derivative	pochodna
integration	całkowanie
integral	całka

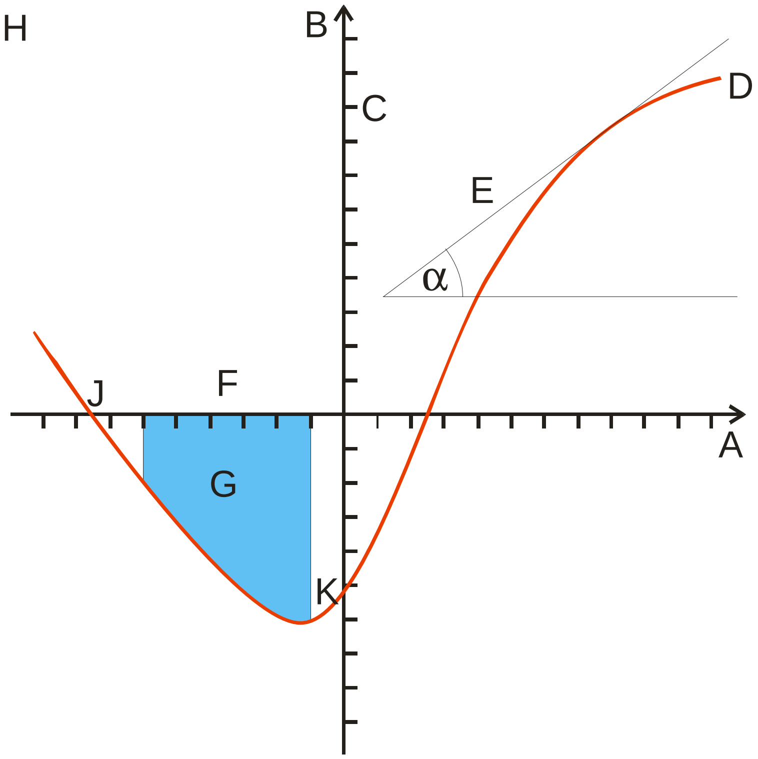
1.2.5. *Functions*

function	funkcja
graph	wykres
coordinates	współrzędne
coordinate system	układ współrzędnych
axis (axes)	oś (osie)
scale	skala
line	prosta

curve	krzywa
slope	nachylenie (prostej, krzywej)
intercept	punkt przecięcia (np. z osiami)
range	zakres, przedział
point	punkt

1.2.6. *Exercise*

1. Label the parts of the graphic representation of a function:



A	curve
B	graph
C	integral in the range (-6;-1)
D	intercept with the *x*-axis
E	intercept with the *y*-axis
F	range (-6;-1)
G	scale
H	slope
J	*x*-axis
K	*y*-axis

1.2.7. *Planar (flat) geometric figures*

segment	odcinek
angle	kąt
side	bok
acute angle	kąt ostry
obtuse angle	kąt rozwarty
right angle	kąt prosty
triangle	trójkąt
equilateral triangle	trójkąt równoboczny
isosceles triangle	trójkąt równoramienny
right-angled triangle	trójkąt prostokątny
Pythagorean theorem	twierdzenie Pitagorasa
quadrilateral	czworokąt
trapezoid; trapezium	trapez
parallelogram	równoległobok
rhombus	romb
rectangle	prostokąt
square	kwadrat

pentagon (regular)	pięciokąt (foremny)
hexagon (regular)	sześciokąt (foremny)
circle	koło
ellipse	elipsa

1.2.8. *Three-dimensional (3-D, spatial) figures*

face	ściana
tetrahedron	czworościan
cube	sześcian
octahedron	ośmiościan
pyramid	ostrosłup
bipyramid	bipiramida
prism	graniastosłup
cylinder	walec
sphere	kula
cone	stożek

1.2.9. *Exercise*

1. Choose the appropriate expressions.

All the angles in an **equilateral / isosceles** triangle are equal and **obtuse / acute**. A square may be viewed as a rectangle with all its **angles / sides** equal or as a rhombus with all its **angles / sides** equal. The Pythagorean **statement / theorem** applies only to **right angles / right-angled triangles**. The benzene ring is usually represented as a regular **pentagon / hexagon**.

The methane molecule has a **tetrahedral / octahedral** shape. Atoms may be imagined as very small **circles / spheres**. An octahedron has eight identical triangular **sides / faces**. A molecule of **phosphorus(III) chloride PCl_3 / phosphorus(V) chloride PCl_5** may take the shape of either a square pyramid or a triangular bipyramid.

1.2.10. *Rounding off*

accurate to *n* decimal places	z dokładnością do *n* miejsc dziesiętnych (po przecinku)
accurate to *n* significant figures	z dokładnością do *n* cyfr znaczących

2. The World of Atoms

2.1. The structure of the atom

For many centuries people believed that matter has a continuous form. The first person who suspected the discrete structure of matter was Democritus, a Greek philosopher living in 460 – 370 B.C. He defined an 'atom' as the smallest, indivisible portion of matter. He claimed that every substance is made up of a large number of specific atoms.

Today we know that Democritus was right about the atomic structure of matter, but that he was wrong about the indivisibility of an atom. All atoms consist of three kinds of elementary particles: protons, neutrons and electrons. The protons and neutrons form the nucleus of the atom, while the electrons move around the nucleus in a complex way. Let us now look at the properties of elementary particles.

Particle	**Mass (kg)**	**Relative mass**	**Relative charge**	**Symbol**
Electron	9.109×10^{-31}	5.45×10^{-4}	-1	*e*
Proton	1.673×10^{-27}	1	+1	*p*
Neutron	1.675×10^{-27}	1	0	*n*

An electron and a proton each carries an electric charge of equal magnitude but of opposite sign. By convention, an electron is assigned a –1 sign (negative), a proton a +1 sign (positive). As atoms are electrically neutral, the number of protons must equal the number of electrons in each atom.

A proton and a neutron have an almost identical mass. An electron, though, is about 1830 times lighter. Since the nucleus is made up exclusively of protons and neutrons, the mass of an atom is concentrated in its nucleus. The nucleus is very small, about 100 000 times smaller than the whole atom. Therefore, an atom is mostly empty space, with a massive but small nucleus in the centre and a diffuse, spherical cloud of electrons around it.

2.1.1. *Reading comprehension*

1. What did Democritus think about the structure of matter?
2. Which of Democritus' predictions were entirely wrong?
3. What are the main components of an atom?
4. How are elementary particles distributed in the atom?
5. What are the relative charges and masses of the elementary particles of an atom?

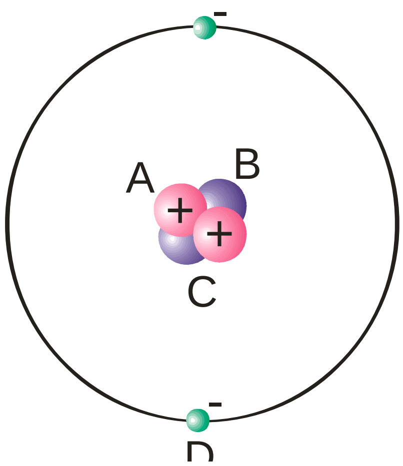
2.1.2. *New terms and expressions*

atom	atom
atomic	atomowy
B.C. (before Christ)	przed naszą erą (przed Chrystusem)
centre (US center)	środek
century	wiek, stulecie
charge	ładunek
claim	utrzymywać, twierdzić, wyrażać sąd
complex	złożony, skomplikowany
concentrate	koncentrować (się), skupiać (się)
continuous	ciągły
convention	umowa, zwyczaj
diffuse	rozmyty, rozproszony
discrete	nieciągły, dyskretny
divisible	podzielny
electric	elektryczny
electron	elektron
elementary particle	cząstka elementarna
equal	jednakowy, równy
exclusively	wyłącznie
identical	identyczny
indivisible	niepodzielny
magnitude	wielkość
mass	masa
massive	masywny, ciężki

matter	materia
move	poruszać się
negative	ujemny
neutral	obojętny
neutron	neutron
nucleus (nuclei)	jądro (jądra)
number	liczba
opposite	przeciwny
positive	dodatni
property	właściwość, cecha
proton	proton
relative	względny
sign	znak
space	przestrzeń
specific	swoisty, swojego rodzaju
spherical	kulisty
structure	budowa, struktura

<u>2.1.3. *Exercises*</u>

1. Label the structural elements of an atom.



A.
B.
C.
D.

electron
neutron
nucleus
proton

2. Fill in the blanks.

a. An atom is built of three types of ....
b. A .... carries a positive ...., while an electron is ....
c. Almost the whole mass of an atom is .... in its ....
d. The charges of a proton and an .... are of equal .... but of different ....
e. The masses of a .... and a .... are approximately the same.
g. We can imagine an atom as a .... with a .... cloud of electrons surrounding a .... in the ....

2.2. Atomic number, mass number and relative atomic mass

The atomic number of an atom is defined as the number of protons it contains. Substances made exclusively of atoms with the same atomic number are called elements. In other words, the atomic number identifies which element is which. The element with atomic number 1 is hydrogen, while the one with atomic number 79 is gold. Since individual atoms are electrically neutral, they contain exactly as many electrons as protons: the hydrogen atom has one electron, the gold atom 79 electrons.

The mass number is the total number of protons and neutrons in an atomic nucleus. The nucleus of hydrogen consists of only one proton. Since there are no neutrons, the mass number of hydrogen is 1. The mass number of gold is 197. This means that apart from 79 protons, the nucleus of the gold atom contains exactly 118 neutrons.

Two atoms may have the same number of protons but a different number of neutrons. Since they have the same atomic numbers, they are atoms of the same element. Atoms of an element differing in the number of neutrons in its nuclei are called isotopes. Some elements, such as fluorine, aluminium, cobalt or gold, exist in nature as single isotopes. But the majority of them occur as a mixture of several isotopes. For example, natural carbon consists of 99% of the ${}^{12}_{6}\mathrm{C}$ isotope, 1% of the ${}^{13}_{6}\mathrm{C}$ isotope and traces of the radioactive ${}^{14}_{6}\mathrm{C}$ isotope.

The ${}^{12}_{6}\mathrm{C}$ isotope has been chosen as the standard for relative atomic mass. The relative atomic mass tells us how many times the average mass of the atom of a given element is larger than 1/12 of the mass of the ${}^{12}_{6}\mathrm{C}$ atom. In contrast to the mass number, which is always an integer, the relative atomic mass is usually a decimal, as it expresses the weighted average mass of all the natural isotopes constituting the element. One can calculate the relative atomic mass of the element knowing the relative abundance of its isotopes.

2.2.1. *Reading comprehension*

1. What is the atomic number of an element?
2. What is the mass number of an element?
3. How many neutrons are there in the nucleus of a gold atom?
4. What is the difference between two isotopes of the same element?
5. Is the mass number always the same as the relative atomic mass?
6. Why is the relative atomic mass usually a decimal?

2.2.2. *New terms and expressions*

abundance (relative)	rozpowszechnienie (względne)
aluminium (US aluminum)	glin
atomic number	liczba atomowa
average	średni, uśredniony
calculate	obliczać
cobalt	kobalt
consist (of)	składać się (z)

constitute	składać się na
decimal	liczba "niecałkowita"
define	definiować, określać
element	pierwiastek
exactly	dokładnie
express	wyrażać
fluorine	fluor
gold	złoto
hydrogen	wodór
identify	określać, rozpoznawać
indicate	wskazywać
individual	poszczególny, pojedynczy
isotope	izotop
majority	większość
mass number	liczba masowa
mixture	mieszanina
nucleus (nuclei)	jądro (jądra)
radioactive	promieniotwórczy, radioaktywny
(relative) atomic mass	(względna) masa atomowa
single	pojedynczy
standard	standard, wzorzec
substance	substancja
total	całkowity
weighted (average)	ważona (średnia)

2.2.3. *Exercises*

1. For the $^{55}_{25}\mathrm{Mn}$ isotope, match the numbers with appropriate descriptions (one number may refer to two or more descriptions).

25
30
55
54.94

atomic number
mass number
number of electrons
number of neutrons
number of protons
relative atomic mass

2. Fill in the blanks.

Natural magnesium .... of three stable .... : $^{24}_{12}\mathrm{Mg}$, $^{25}_{12}\mathrm{Mg}$ and $^{26}_{12}\mathrm{Mg}$. The relative .... of each is 79, 10 and 11% respectively. The ....… atomic mass of magnesium can be calculated as a .... in the following way: $\frac{24 \cdot 79\% + 25 \cdot 10\% + 26 \cdot 11\%}{100\%}$ = 24.32.

2.3. Radioactivity

The nuclei of some, usually heavy, isotopes are unstable. They possess an excess of energy that is released in the form of radiation. Such isotopes are referred to as radioactive isotopes or radioisotopes. While emitting radiation, radioisotopes are gradually converted into other isotopes. This process is termed radioactive decay. There are three general types of radioactive decay: alpha, beta and gamma.

In alpha decay, the nuclei of the parent isotope emit alpha particles, each of which consists of two protons and two neutrons. The daughter isotope is a different element, since the nucleus contains two protons fewer.

In beta decay, a nucleus loses an electron, which is produced by transformation of one neutron to a proton. Again, the daughter isotope is a new element with one proton more in the nucleus.

Gamma decay involves the emission of high-energy, short-wave electromagnetic radiation. The nuclei of the daughter isotope have the same composition as those of the parent isotope.

Alpha radiation consists of large, heavy alpha particles (helium-4 nuclei, in fact). Since such particles interact strongly with other atoms, alpha radiation can be stopped even by a piece of thin metal or plastic foil. Beta radiation is a stream of electrons, which are small and can penetrate much further than alpha particles. Gamma radiation is even more penetrative: it can only be stopped by thick lead or concrete blocks.

The rate of radioactive decay is a first-order reaction. This means that the same fraction of the radioactive isotope decays in unit time. The time required for the isotope to decay to exactly half its original amount is known as its half-life. The half-lives of isotopes may vary over a very wide range, from fractions of a second to billions of years.

It is important not to confuse radioactive decay with nuclear fission. Nuclear fission involves the decomposition of a nucleus to smaller fragments, induced by the absorption of a neutron. A large amount of energy is evolved in this process. It can be utilized when nuclear fission is under full control, as in nuclear power plants.

2.3.1. *Reading comprehension*

1. Why do some nuclei emit radiation?
2. What is radioactive decay?
3. What is the nature of alpha, beta and gamma decay?
4. Why do alpha, beta and gamma rays penetrate different distances?
5. What is the kinetics of radioactive decay?
6. What does the term ‘half-life’ mean?
7. What is the difference between radioactive decay and nuclear fission?

2.3.2. *New terms and expressions*

absorption	absorpcja, pochłanianie
amount	ilość
billion	miliard
concrete	beton
confuse	pomylić, pomieszać
daughter isotope	izotop potomny
decay (radioactive)	rozpad (promieniotwórczy)
decomposition	rozkład, rozpad
electromagnetic	elektromagnetyczny
emission	emisja
evolve	wydzielać (się)
excess	nadmiar
first-order	pierwszego rzędu
fission (nuclear)	rozszczepienie (jądrowe)
foil	folia
fragment	fragment
gradually	stopniowo
half-life	okres połowicznego zaniku
handle	obchodzić się (z)
induce	wywołać, spowodować
interfere	oddziaływać
involve	polegać (na), angażować
lead	ołów
metal	metal
parent isotope	izotop macierzysty
penetrate	przenikać
penetrative	przenikliwy
plastic	tworzywo sztuczne, polimer, plastik
power plant (nuclear)	elektrownia (jądrowa)
process	proces
production	wytwarzanie
radiation	promieniowanie
radioisotope	izotop promieniotwórczy

rate (of a reaction)	szybkość (reakcji)
reaction	reakcja
release	uwolnić, wydzielić
require	wymagać
rubber	guma
short-wave	krótkofalowy
stream	strumień
transform	przekształcić (się), zmienić (się)
transformation (conversion)	przemiana
unstable	niestabilny, nietrwały

2.3.3. *Exercises*

1. Match the passages to form complete, correct statements.

The nuclei of radioisotopes	are the same as helium nuclei.
Alpha particles	are unstable.
Beta particles	bear a negative electric charge.
Gamma rays	is a first-order reaction.
Radioactive decay	produces a lot of energy.
Nuclear fission	propagate through space in the same way as an electromagnetic wave.

2. Indicate which statements are true (T) or false (F).

a. Alpha radiation is a stream of negatively charged particles. T / F

b. Lead blocks effectively stop gamma radiation. T / F

c. Uranium is an alpha-emitter, so it is safe to handle it with rubber gloves. T / F

d. The parent isotope and the daughter isotope are always different elements. T / F

e. The half-life of radioisotopes may be as long as several hundred years. T / F

f. Nuclear fission is just another name for radioactive decay. T / F

3. Choose appropriate phrases.

Radioisotopes **reduce / release** excess energy in the form of **radiation / decay**. During the process of radioactive **decay / decomposition**, the **mother / parent** isotope transforms into a **daughter / child** isotope. Alpha particles penetrate a **longer / shorter** distance than beta particles do. After two half-lives, the original amount of radioisotope is reduced to one **third / fourth**. In the process of nuclear fission, a **nucleus / testicle** breaks up into several smaller fragments.

3. Electron Configuration. Periodic Table

3.1. The electron configuration of an atom.

The electrons circling around an atomic nucleus do not move in entirely random fashion. Their energy is quantized: this means that they can take only specific energy values. This also limits the space within which a given electron can be found.

The position of any electron is determined by four quantum numbers:

Name	Symbol	Values	Structural element	Symbols for the structural elements
principal quantum number	n	$n = 1, 2, 3, \ldots$	shell	*K, L, M, ...*
azimuthal quantum number	l	$l = 0, 1, \ldots, n\text{-}1$	subshell	*s, p, d, ...*
magnetic quantum number	m_l	$m_l = -l, -(l - 1), \ldots,$ $-1, 0, 1, \ldots, l\,-1, l$	orbital	$s, p_x, p_y, p_z, \ldots$
electron spin quantum number	m_s	$m_s = -½, +½$	direction of electron spin	↓↑

The principal quantum number *n* defines the electron shell of an atom. Electron shells are split into subshells, defined by the azimuthal quantum number *l*. Subshells in turn split into a set of degenerate orbitals. Each orbital holds two electrons of opposite spins. Pauli's exclusion principle states that no two electrons in an atom may have the same set of four quantum numbers.

Every element has its own, unique distribution of electrons throughout the atomic orbitals – this is referred to as the electron configuration of an atom. The number of electrons in the outermost, valence shell (subshell) defines the chemical properties of an element. Two different elements with the same number of valence electrons have similar chemical properties.

3.1.1. *Reading comprehension*

1. What do we mean when we say that the energy of an electron is quantized?
2. What are the four quantum numbers?
3. How are quantum numbers related to the structural elements of an atom?
4. Which electrons define the chemical properties of an element?

3.1.2. *New terms and expressions*

azimuthal quantum number	poboczna liczba kwantowa
degenerate	zdegenerowany (o tej samej energii)
distribution	dystrybucja, rozmieszczenie
electron configuration	konfiguracja elektronowa
electron spin quantum number	spinowa liczba kwantowa
indicate	wskazywać
limit	ograniczać
magnetic quantum number	magnetyczna liczba kwantowa
maximum	maksimum, maksymalny
orbital	orbital
Pauli's exclusion principle	zakaz Pauliego
principal quantum number	główna liczba kwantowa
quantize	kwantować
quantum number	liczba kwantowa
random	przypadkowy, losowy
set	układ, zestaw
shape	kształt
shell	powłoka
spin	spin
split	rozszczepiać (się)
subshell	podpowłoka
take (assume)	przyjmować
valence	walencyjny

3.1.3. *Exercise*

1. Match the following phrases:

aziumthal quantum number	the number of *d* orbitals
degenerate	assuming only specific values
electron configuration	defines the type of subshell
electron spin quantum number	defines the electron shell
electrons in the outermost shell (subshell)	determines the shape of the orbital
five	distribution of electrons throughout the atom
magnetic quantum number	indicates the direction of the electron spin
prinicpal quantum number	the maximum number of electrons in a single orbital
quantized	of the same energy
two	valence electrons

3.2. The periodic table of the elements

The periodic table lists all the elements known (and in fact, those that are not yet known). They are organized in horizontal rows, called periods, and vertical columns, called groups. Within a period, the element placed to the right of another element has one proton (and electron) more than its neighbour, so the atomic numbers of the elements increase regularly across the period. Within a group, all the elements have a similar configuration of valence electrons, so their properties are similar.

When we examine how the properties of elements change with their position in the periodic table, we can observe many regularities. For example, atomic radii decrease from left to right across the period, but they increase from top to bottom down the group. On the other hand, electronegativity and the first ionization energy exhibit the opposite trend.

The periodic table is usually divided into three distinct sections: the *s*-, *p*- and *d*-blocks. Sometimes the *s*- and *p*-blocks together are called the main groups. The elements of some groups have been given specific names. The group 1 elements are called the alkali metals, while those in group 2 are known as the alkaline earth metals. Similarly, the elements of group 7 are often referred to as the halogens, and those of group 8 are the noble gases. The elements in the *d*-block are collectively referred to as the transition elements or transition metals; they include two separate rows of lanthanides and actinides. The non-metals are grouped in the upper right-hand corner of the periodic table, while the rest of the table is occupied by metals, except for the few metalloids, which lie on the borderline between the two.

3.2.1. *Reading comprehension*

1. How is the periodic table organized?
2. Why do elements in the same group have similar chemical properties?
3. What trends can be observed in the periodic table?
4. What are the names of the groups in the *s*-block?
5. Where should you look for non-metals in the periodic table?

3.2.2. *New terms and expressions*

actinides	aktynowce
alkali metals	metale alkaliczne, litowce
alkaline earth metals	metale ziem alkalicznych, berylowce
block	blok
borderline	granica, linia graniczna
collectively	łącznie, razem
column	kolumna
class	kategoria, typ
decrease	maleć, zmniejszać się
distinct	wyraźny, odrębny
divide	dzielić
electronegativity	elektroujemność

exhibit	wykazywać, pokazywać, przedstawiać
group	grupa
halogens	halogeny, fluorowce
horizontal	poziomy
include	zawierać, włączać
increase	wzrastać, zwiększać się
ionization energy	energia jonizacji
lanthanides	lantanowce
list	wymieniać, wyszczególniać
main	główny
metal	metal
metalloid (semi-metal)	metaloid, półmetal
neighbour (US neighbor)	sąsiad
noble gases	gazy szlachetne, helowce
non-metal (nonmetal)	niemetal
organize	układać, porządkować, organizować
period	okres
periodic table	układ okresowy
position	położenie
radius (radii)	promień (promienie)
reverse	odwrotny
row	rząd
section	część, fragment
transition elements	pierwiastki przejściowe
transition metals	metale przejściowe
trend	tendencja, trend
vertical	pionowy

3.2.3. *Exercises*

1. Fill in the blanks

Phosphorus is a typical .... It is placed in the third .... and in the fifteenth .... of the .... This means that the phosphorus atom has three electron .... and five .... electrons. The elements to the right of phosphorus are ...., while those to the left and below are .... The nearest .... – silicon, germanium and arsenic – belong to the class of ....

2. Indicate which of the following statements are true (T) or false (F).

a. The metallic character of elements increases across the period (from left to right). T / F
b. Electronegativity increases across the period and decreases down the group. T / F
c. Magnesium is a main group element. T / F
d. Iron is a typical *p*-block element. T / F
e. The lanthanides include ten elements. T / F
f. All elements with an atomic number greater than 88 are actinides. T / F
g. All *d*-block elements are transition metals. T / F

3.3. The names and symbols of the elements

Some elements, such as gold, silver, copper, lead, iron, tin or sulphur have been known to man for millennia. Their names are traditional and specific for a particular language: compare English 'iron' with Italian 'ferro', German 'Eisen' or Polish 'żelazo', and English 'lead' with Italian 'piombo', German 'Blei', Polish 'ołów' and Russian 'svinec'.

The names of the other elements are spelt and sound similar in different languages because they usually have a common origin. For example, some elements were named after their distinctive properties: chlorine was named after its colour (Greek *chloros* means yellow-green), so it is 'cloro' in Italian, 'Chlor' in German and 'chlor' in Polish. The name ‘phosphorus’ (Greek *phos* 'light' and *phoros* 'bearer') was derived in a similar way.

Many elements were named after mythical characters, geographical areas, astronomical objects or famous scientists, for example:

mercury Hg	Mercury, agile messenger of Jupiter, Roman god of trade, profit and commerce.
vanadium V	Vanadis, Scandinavian goddess of beauty
helium He	Helios, Greek god of the Sun, impersonation of the Sun
selenium Se	Selene, Greek goddess of the Moon
uranium U	Uranus, the seventh planet from the Sun
europium Eu	Europe (continent)
americium Am	America (continent)
scandium Sc	Scandinavia (region)
rhenium Re	Rhine (river in Germany)
polonium Po	Poland (country)
californium Cf	California (state in the USA)
mendelevium Md	Mendeleev (Russian chemist)
einsteinium Es	Einstein (physicist)

Chemists use symbols to identify elements. Each element has its own, unique symbol consisting of one or two letters and is usually derived from its Latin name.

3.3.1. *Reading comprehension*

1. Which elements have been known to man since ancient times?
2. What is the colour of chlorine?
3. What could be the origin of the name 'mercury'?
4. Which elements have ‘geographical’ names?

3.3.2. *New terms and expressions*

agile	ruchliwy
astronomy	astronomia
californium	kaliforn
character	postać
chemist	chemik
chlorine	chlor
colour (US color)	kolor, barwa
commerce	sprzedaż
compare	porównywać
continent	kontynent
copper	miedź
country	kraj, państwo
derive	wyprowadzić (w sensie wywieść)
distinctive	wyróżniający się, charakterystyczny
einsteinium	einstein
europium	europ
famous	sławny, słynny
geography	geografia
god	bóg
goddess	bogini
helium	hel
iron	żelazo
language	język
Latin	łaciński, łacina
mendelevium	mendelew
mercury	rtęć
messenger	posłaniec
millennium (millennia)	tysiąclecie (tysiąclecia)
mythical	mityczny
object	przedmiot, obiekt
origin	pochodzenie, źródło
particular	określony, szczególny
phosphorus	fosfor

physicist	fizyk
planet	planeta
polonium	polon
profit	zysk
region	kraina, region
rhenium	ren
river	rzeka
scandium	skand
scientist	naukowiec, badacz
selenium	selen
silver	srebro
sound	brzmieć
spell	pisać (w sensie pisowni)
state	stan
sulphur (US sulfur)	siarka
symbol	symbol
tin	cyna
trade	handel
traditional	tradycyjny
unique	unikalny, jedyny, swoisty
uranium	uran
vanadium	wanad

3.3.3. *Exercises*

1. Give the names of the following elements:

has an atomic number of 47	
has a relative atomic mass of about 238	
lies between cobalt and copper in the periodic table	
lies below cadmium in the periodic table	
lies in the 5th period and in group 15	
the lightest element of group 17	
the heaviest element of group 18	
ends the lanthanide series	
starts the second row of transition metals	
takes part in all combustion reactions	

2. Group the names of the following elements according to their possible origin: barium, bohrium, bromine, chromium, darmstadtium, dubnium, fermium, gallium, germanium, indium, iodine, neptunium, nobelium, phosphorus, plutonium, radium, silver, sulphur, tantalum, technetium, thorium, tin, titanium.

Traditional name	
Mythical character	
Astronomical object	
Geographical name	
Named after a famous person	
Distinctive property	

4. Chemical Bonding

Atoms are linked by chemical bonds. There are four general types of bond: ionic, covalent, coordinate and metallic.

4.1. Covalent and coordinate bonds

A covalent bond is formed when two atoms share their unpaired valence electrons. Each shared pair of electrons gives rise to a single bond. Atoms linked by covalent bonds usually form molecules or polyatomic ions, for example, the hydrogen molecule H_2, the hydrogen chloride molecule HCl or the hexafluorophosphate anion PF_6^-. Some atoms show a tendency to form multiple bonds. For example, two carbon atoms can be linked by a single bond (as in ethane $CH_3–CH_3$), a double bond (as in ethene $CH_2=CH_2$) or a triple bond (as in ethyne $HC≡CH$).

When two bonded atoms differ in their electronegativity, the bonding electron pair is shifted towards the more electronegative atom. In this case, a partial negative charge appears on the more electronegative atom, and a partial positive charge on the less electronegative one. Such a bond resembles an electrical dipole and is referred to as a polar or polarized covalent bond. Molecules containing polarized bonds are usually polar, although this is not always the case. For example, both C=O bonds in the carbon dioxide molecule are polar, but the molecule as a whole is not polar, since the individual dipole moments of both bonds cancel each other out. In general, every covalent bond is polar to some extent, unless the bond occurs between two atoms of the same kind, as in the case of H_2, Cl_2, P_4 or S_8 molecules.

Sometimes, atoms linked by covalent bonds do not form separate molecules but produce a giant, three-dimensional structure. Examples of giant covalent structures include diamond and graphite (allotropic forms of carbon), silicon dioxide SiO_2 or aluminosilicate anions.

A coordinate bond (dative bond) is a kind of covalent bond in which the whole bonding electron pair is provided by one of the linked atoms. Coordinate bonds are typical of transition metal ions, whose empty *d*-orbitals act as acceptors of electron pairs from donor atoms incorporated in ligands.

4.1.1. *Reading comprehension*

1. How is a covalent bond formed?
2. Do covalent bonds occur only in molecules?
3. What types of bonds occur in nitrogen and oxygen molecules?
4. Can a covalent bond link two atoms of the same kind?
5. Which type of covalent bond do we call a polar bond?
6. What is the difference between a covalent bond and a coordinate bond?
7. Which is the acceptor and which is the donor in the $[Cu(H_2O)_6]^{2+}$ ion?

4.1.2. *New terms and expressions*

acceptor	akceptor
allotrope, allotropic form	odmiana alotropowa
aluminosilicate	glinokrzemian
anion	anion
appear	pojawiać się
bond	wiązanie
bonding electron pair	wiążąca para elektronowa
by means of	za pomocą
cancel (each other) out	kasować się (wzajemnie)
carbon	węgiel (pierwiastek)
carbon dioxide	dwutlenek węgla
cation	kation
coordinate or dative bond	wiązanie koordynacyjne
covalent bond	wiązanie kowalencyjne
crosslink	sieciować, łączyć wzajemnie
dipole	dipol
dipole moment	moment dipolowy
distance	odległość
donor	donor
double bond	wiązanie podwójne
ethane	etan
ethene	eten
ethyne	etin

giant structure	struktura makromolekularna
hexafluorophosphate	heksafluorofosforan
incorporated	włączony, znajdujący się w
ionic bond	wiązanie jonowe
ligand	ligand
link	łączyć się
metallic bond	wiązanie metaliczne
molecule	cząsteczka, molekuła
multiple bond	wiązanie wielokrotne
pair	para
partial charge	ładunek cząstkowy
polar	polarny
polarized	spolaryzowany
polyatomic ion	jon wieloatomowy
share	dzielić, uwspólniać
shift	przesunąć
silicon dioxide	dwutlenek krzemu
single bond	wiązanie pojedyncze
solid	ciało stałe
solution	roztwór
to some extent	w pewnym stopniu
triple bond	wiązanie potrójne
unpaired	niesparowany

4.1.3. *Exercises*

1. Match the appropriate phrases.

a bond in bromine Br_2

a carbon – chlorine bond in chloroform $CHCl_3$

a large number of atoms crosslinked by covalent bonds

the carbon – sulphur bond in carbon disulphide CS_2

a charged group of a few atoms linked by covalent bonds

a covalent bond

an empty *d*-orbital in a transition metal ion

a neutral group of a few atoms linked by covalent bonds

the nitrogen – carbon bond in hydrogen cyanide HCN

the nitrogen atom in the ammonia molecule

partial electric charges of opposite sign separated by a certain distance

the shared electron pair comes from one of the bonded atoms

acceptor

coordinate bond

giant covalent solid

dipole

donor

double bond

molecule

non-polarized single covalent bond

polarized single covalent bond

polyatomic ion

shared electron pair

triple bond

2. Fill in the blanks.

A .... of sulphuric(VI) acid H_2SO_4 consists of .... atoms. All the atoms are linked by .... bonds. There are four .... bonds and two .... bonds in the molecule. Since the electronegativities of hydrogen, oxygen and sulphur are 2.1, 3.5 and 2.5 respectively, all these bonds are .... In aqueous solution, the H_2SO_4 molecule loses two hydrogen .... to form the .... charged .... SO_4^{2-} ion. Most probably, the SO_4^{2-} anion assumes a .... shape.

In the complex $[Ag(CN)_2]^-$ ion, the central .... ion is surrounded by two cyanide .... The metal ion acts as the .... of electron pairs, while the carbon atoms of the cyanide ions act as the .... The metal ion is linked to the ligands by two .... bonds.

4.2. Ionic and metallic bonds

When the difference in electronegativity between two bonded atoms is sufficiently large, the whole bonding pair may be transferred to the more electronegative atom. In this way a pair of ions is formed. The more electronegative atom, of high electron affinity, accepts one or more electrons to form a negative ion, an anion, whereas the less electronegative atom, of low ionization energy, loses one or more electrons to form a positive ion, a cation. Oppositely charged ions attract one another with strong electrostatic forces. This type of bond is referred to as an ionic or electrovalent bond.

In the solid state, ions are packed tightly to form a regular giant structure known as an ionic crystal. The strong intermolecular forces are reflected by the properties of ionic compounds: they are hard, brittle solids with high melting points.

Sodium chloride NaCl is an example of an ionic compound. The cubic crystals of NaCl consist of alternating layers of sodium and chloride ions, where each Na^+ ion is surrounded by six Cl^- ions and, conversely, each Cl^- ion is surrounded by six Na^+ ions. It is important to understand that there is no such thing as an NaCl molecule: the formula ‘NaCl’ merely indicates that there are exactly as many sodium ions as chloride ions in the giant structure of the ionic crystal.

Metallic bonds occur in metals and metal alloys. In a solid metal, all the atoms are ionized to form cations. These ions are stacked regularly in a crystal lattice. The electrons lost as a result of ionization form a common, negatively charged cloud referred to as an 'electron sea'. The electrons are delocalized over the whole giant structure of the metallic crystal and are free to move. The 'electron sea' acts as a kind of 'negative glue' that holds the positive ions together, which otherwise would be pushed apart by repulsive forces. The 'electron sea' model explains many of the properties common to metals: conductivity of electricity and heat, malleability, ductility, as well as their grey colour (except for copper and gold) and metallic lustre.

4.2.1. *Reading comprehension*

1. How are valence electrons distributed in two atoms linked by an ionic bond?
2. What forces keep the ions in an ionic crystal together?
3. Do oppositely charged ions form neutral species consisting of a few atoms, such as molecules?
4. What are typical properties of ionic compounds?
5. How would you classify stainless steel?
6. How does the 'electron sea' model explain the internal structure of a metal?
7. Why do you think metals conduct electricity and heat whereas ionic crystals do not?

<u>4.2.2. *New terms and expressions*</u>

act	działać, funkcjonować, pełnić rolę
alloy	stop (metali)
alternating	naprzemienny
apart	od siebie
aqueous	wodny
attract, attraction	przyciągać, przyciąganie
brittle	kruchy
chloride ion	jon chlorkowy
common	wspólny
conductivity	przewodnictwo
conversely	odwrotnie
crystal lattice	sieć krystaliczna
cubic	sześcienny
delocalize	zdelokalizować
ductility	ciągliwość
electron affinity	powinowactwo elektronowe
electron sea	? [morze elektronów ?]
electrostatic force	siła elektrostatyczna
electrovalent bond	wiązanie elektrowalencyjne (jonowe)
explain	tłumaczyć
formula	wzór
glue	klej
hammer	młotek
hard	twardy
heat	ciepło
hold	trzymać
intermolecular forces	siły międzycząsteczkowe
internal	wewnętrzny
ionic compound	związek jonowy
ionic crystal	kryształ jonowy
layer	warstwa
lustre (US luster)	połysk
malleability	kowalność

melting point (MP, m.p.)	temperatura topnienia
pack	pakować, upakowywać
push	pchać
reflect	odbijać, odzwierciedlać
regular	uporządkowany
repulse, repulsion, repulsive	odpychać, odpychanie, odpychający
sodium chloride	chlorek sodu
sodium ion	jon sodu
stack	ułożyć, upakować
stainless steel	stal nierdzewna
sufficiently	wystarczająco, odpowiednio
tight	ciasny
transfer	przenieść

4.2.3. *Exercises*

1. Indicate which statements are true (T) or false (F).

a.	The formation of an ionic bond between two atoms of the same electronegativity is not possible.	T / F
b.	When two atoms are linked by an ionic bond, the more electronegative atom forms a cation.	T / F
c.	Only attractive forces operate within an ionic crystal.	T / F
d.	The formula $CaCl_2$ means that in the molecule of calcium chloride, each calcium atom is linked to two chlorine atoms by single covalent bonds.	T / F
e.	All metals and ionic crystals are giant structures.	T / F
f.	Metal cations attract one another in the crystal lattice of a metallic crystal.	T / F
g.	When hit by a hammer, brittle solids break up into smaller fragments, whereas malleable solids change shape but do not break up.	T / F

2. What properties of a metal determine its particular use? Choose from the following list: colour, ductility, electrical conductivity, thermal conductivity, high melting point, malleability, mechanical strength, metallic lustre

a.	Aluminium in cooking pots.	
b.	Copper in electric cables.	
c.	Silver in mirrors.	
d.	Titanium in rocket engines.	
e.	Steel in bridge construction.	
f.	Gold in jewellry	
g.	Iron in hand-made horseshoes.	

3. Examine the structure of sodium ethanoate CH_3COONa and choose suitable answers.

Type of entity	covalent / ionic / coordinate / metallic
Structure in the solid state	crystal consisting of separate molecules / a giant solid
$[Na^+]$	atomic ion / polyatomic ion / molecule
$[CH_3COO^-]$	atomic ion / polyatomic ion / molecule
Carbon – hydrogen bond	a. slightly polarized covalent bond / highly polarized covalent bond / ionic bond b. single bond / double bond / triple bond
Carbon – oxygen bond (no charge on the oxygen atom)	a. slightly polarized covalent bond / highly polarized covalent bond / ionic bond b. single bond / double bond / triple bond
Carbon – oxygen bond (an electrical charge on the oxygen atom)	a. slightly polarized covalent bond / highly polarized covalent bond / ionic bond b. single bond / double bond / triple bond

5. 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

5.1. 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 5.1.1. 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

5.1.1. *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?

5.1.2. *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	znajdujący się w handlu
communication	porozumiewanie (się)
cyanate, isocyanate	cyjanian, izocyjanian
cyanide	cyjanek
detergent	proszek do prania
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

5.1.3. *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

5.2. 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 5.2.1. 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

5.2.1. *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?

5.2.2. *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

5.2.3. *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.	

5.3. 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 5.3.1. 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.

5.3.1. *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?

5.3.2. *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

5.3.3. *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 ....

6. Naming Inorganic Compounds. Part II.

6.1. 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 5.3.1. 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:

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

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

6.1.1. *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?

6.1.2. *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	wydech (w samochodzie)
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)

6.1.3. *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.

6.2. 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.

6.2.1. *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 6.2.1. 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)

6.2.2. *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	liczba rzymska
still	wciąż

6.2.3. *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	

6.3. 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.

6.3.1. *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 6.3.1. 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 6.3.2. 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

6.3.2. *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

6.3.3. *Exercises*

1. Give the names of the following salts.

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

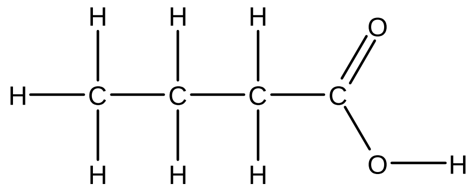
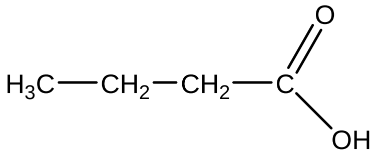
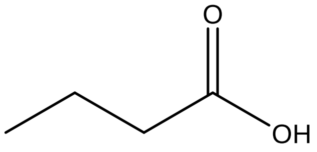
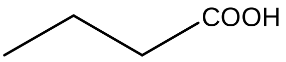
2. Give the names of salts according to their colour, then give their formulae. Choose your answers from the following list: chromium(III) nitrate nonahydrate, cobaltous chloride dihydrate, copper(II) sulphate pentahydrate, ferric chloride hexahydate, ferrous chloride tetrahydrate, iron(III) ammonium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

7. Organic Molecules

7.1. 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

7.1.1. *Reading comprehension*

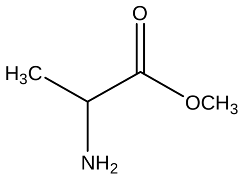
1. How do chemists represent molecules?
2. What is the difference between an empirical formula and a molecular formula?
3. Which types of formulae show how atoms are linked by chemical bonds?
4. How do skeletal structures represent organic molecules?
5. What is general formula of aliphatic alcohols?

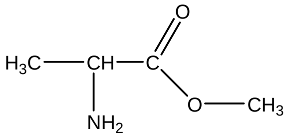
7.1.2. *New terms and expressions*

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

7.2.3. *Exercises*

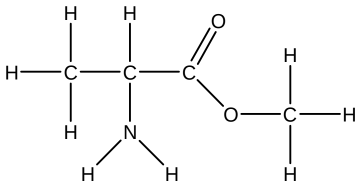
1. Match the type of formula to each representation of the alanine methyl ester molecule.

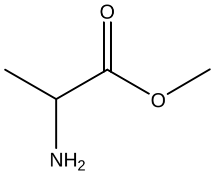




$CH_3CH(NH_2)COOCH_3$

$C_4H_9O_2N$





empirical formula

molecular formula

expanded formula

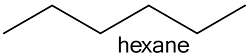
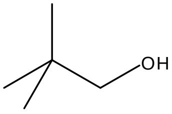
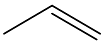
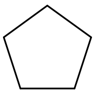
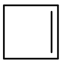
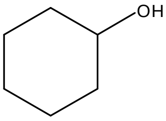
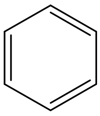
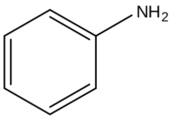
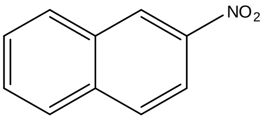
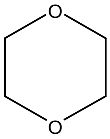
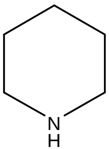
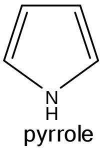
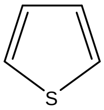
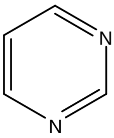
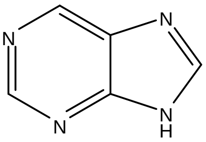
condensed formula

skeletal structure

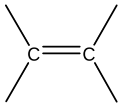
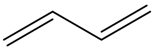
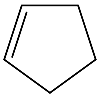
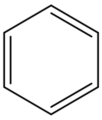
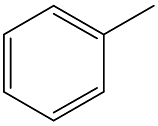
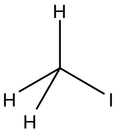
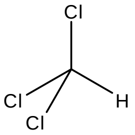
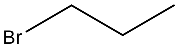
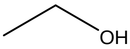
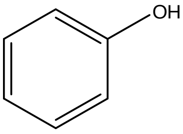
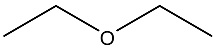
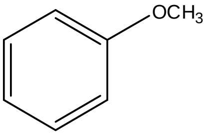
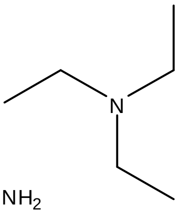
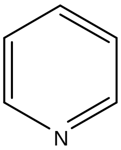
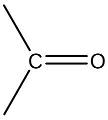
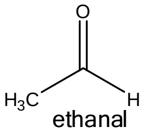
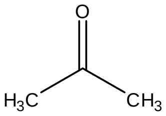
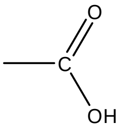
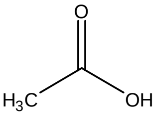
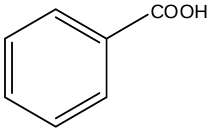
7.2. Classification of organic molecules

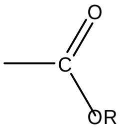
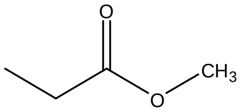
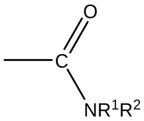
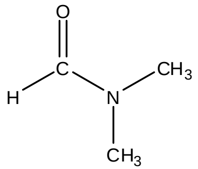
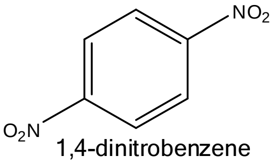
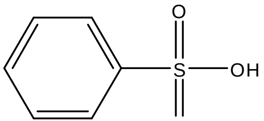
In general, organic molecules are classified according to their specific structural features. The overall shape of the carbon backbone and the presence of functional groups are two of the most important criteria.

The carbon backbone classification is shown in the table below:

Category	**Description**	**Examples**
Aliphatic	Contains a straight or a branched chain of carbon atoms.	 hexane  2,2-dimethylpropanol  propene
Alicyclic	Contains at least one ring of carbon atoms; the π electrons **are not** delocalized over the ring.	 cyclopentane  cyclobutene  cyclohexanol
Aromatic	Contains at least one ring of carbon atoms; the π electrons **are** delocalized over the ring.	 benzene  aniline  2-nitronaphthalene
Heterocyclic	Contains a ring in which at least one atom is not a carbon atom.	 dioxane  piperidine  pyrrole
Heteroaromatic	Contains a ring in which at least one atom is not a carbon atom; the π electrons are delocalized over the ring.	 tiophene  pyrimidine  purine

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

7.2.1. *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?

7.2.2. *New terms and expressions*

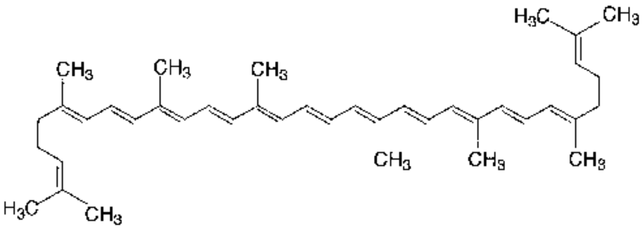
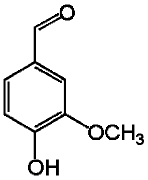
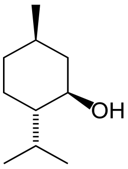
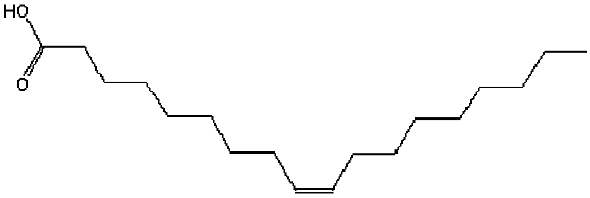
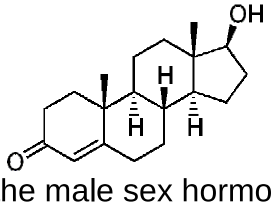
active	czynny
aldehyde	aldehyd
alicyclic	alicykliczny
aliphatic	alifatyczny
alkaloid	alkaloid
alkene	alken
alkoxyl group	grupa alkoksylowa, eterowa

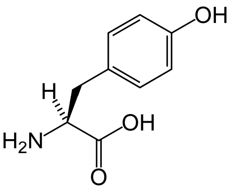
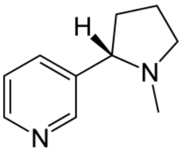
alkyne	alkin
amide	amid
amide group	ugrupowanie amidowe
amine	amina
amine group	grupa aminowa
arene	aren, pochodna benzenu
aromatic	aromatyczny
at least	co najmniej
benzene	benzen
branched	rozgałęziony
carbon backbone	szkielet węglowy (dosł. kręgosłup)
carbonyl group	grupa karbonylowa
carboxyl group	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	trójgliceryd
tyrosine	tyrozyna
unsaturated compound	związek nienasycony
vanillin	wanilina

7.2.3. *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	

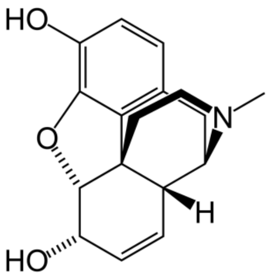
8. Naming Organic Compounds

8.1. 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

8.1.1. *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?

8.1.2. *New terms and expressions*

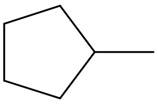
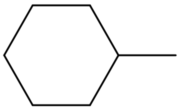
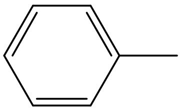
according to	zgodnie z
account for	wykazać, wciąć pod uwagę
adherence	przyleganie, tu: postępowanie zgodne z
arrangement	układ, ułożenie
attach	przyłączyć, przytwierdzić
awkward	niezręczny, dziwny, trudny
comprehensible	zrozumiały
devise	opracować, wymyślić
explicit	oczywisty, jednoznaczny
for the sake 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 8.1.1. 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

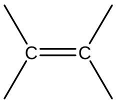
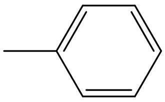
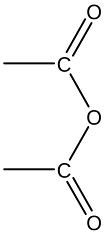
Table 8.1.2. Names of alkyl, cycloalkyl and aryl groups*

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 8.1.3. 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-methylaminomethane, dimethylamine
tertiary amines	–NRR'	N-alkyl-N-alkylamino-	-amine	N-ethyl-N-methylaminopropane, ethylmethylpropylamine
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 8.1.4. 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 8.1.5. Prefixes indicating the number of side groups of the same kind.

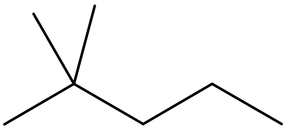
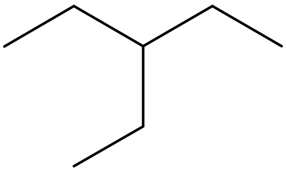
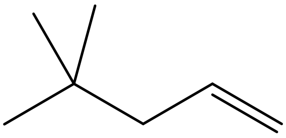
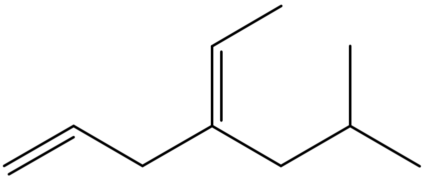
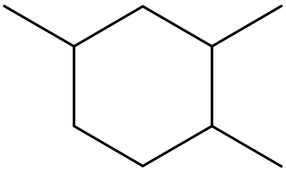
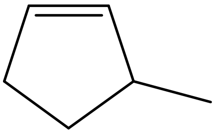
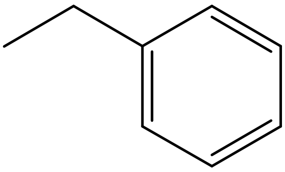
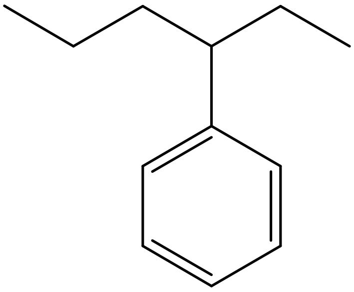
Number of groups	Prefix
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-

Table 8.1.6. 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.

8.1.3. *Exercises*

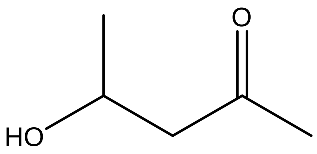
1. Give the names of the following hydrocarbons

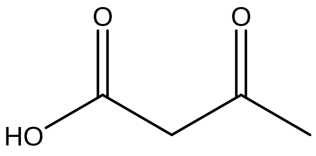









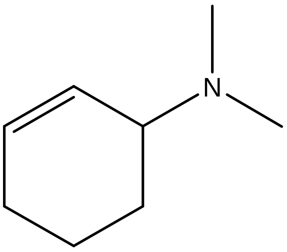
2. Draw the formulae of the following compounds:

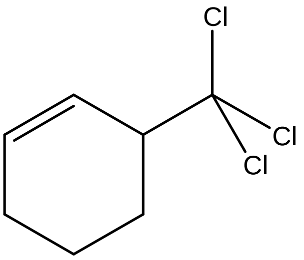
a.	4-chloropentan-2-one	
b.	cyclohexyl propanoate	
c.	3-aminobutanoic acid	
d.	1,1,3-trichlorocyclohexane	
e.	N-methyl-2-chloroethanamide	
f.	prop-2-en-1-ol	
g.	benzoic ethanoic anhydride	
h.	2-nitrobenzenesulphonic acid	
i.	N-methyl-3-ethylcyclohexylamine	
j.	2,4,6-trinitrophenol	

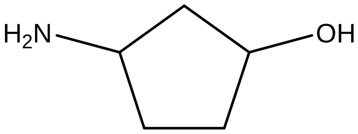
3. Give the systematic names of the following compounds:

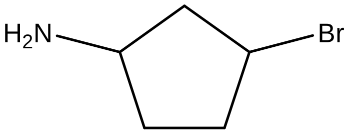




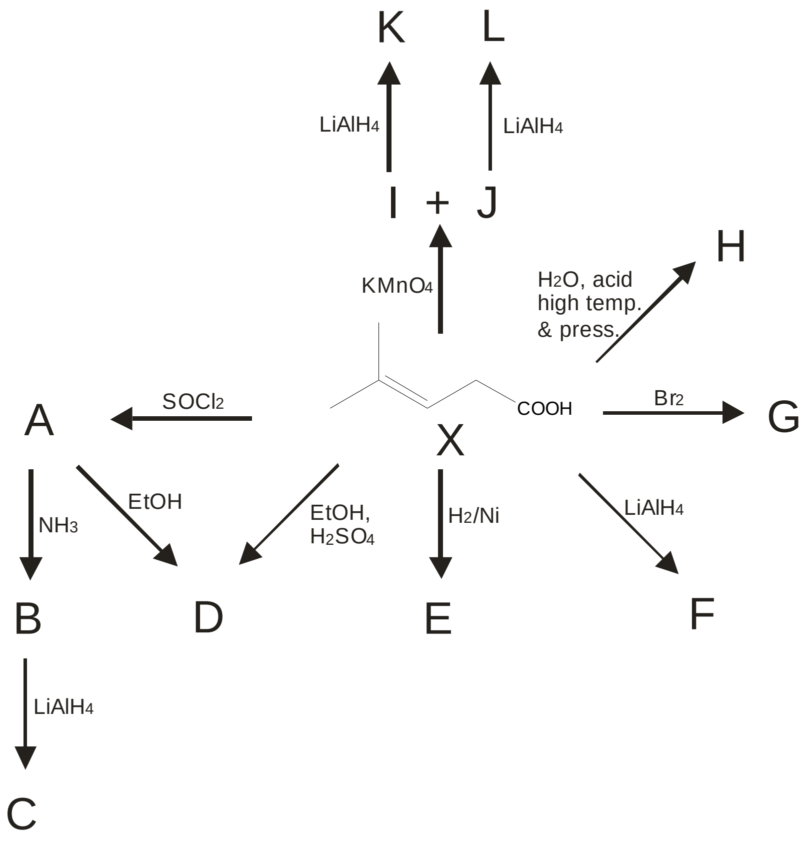








4. Name compound X, then all the reaction products A – L



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

9. 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.

9.1. 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°C (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°C, 161 g at 55°C and 339 g at 91°C. 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°C. 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°C.

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°C 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%).

9.1.1. *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?

9.1.2. *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	przyzwoicie, nieźle
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

9.1.3. *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

9.2. 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^{o}C, boiling point 249^{o}C, flash point 115^{o}C, 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%).

9.2.1. *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?

9.2.2. *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

9.2.3. *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 9.2.1.** 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 9.2.1.** Match the pieces of laboratory apparatus with the materials they are made from.

glass

porcelain

metal

plastic

rubber

cork

paper

conical flask

stopper

hose

bulb

glove box

Büchner funnel

spoon

crucible

burette

thermometer

Bunsen burner

filter

tongs

separating funnel

Table 9.2.1. 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	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

10. Chemical Analysis

10.1. 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.

10.1.1. *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?

10.1.2. *New terms and expressions*

analytical test	test analityczny, próba
brick	cegła
bromine water	woda bromowa
cloudy	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

10.1.3. *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 ....

10.2. 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 10.2.1. 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

10.2.1. *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?

10.2.2. *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

10.2.3. *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.

11. Chromatography

11.1. 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.

11.1.1. *Reading comprehension*

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

11.1.2. *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

11.1.3. *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

11.2. 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.

11.2.1. *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?

11.2.2. *New terms and expressions*

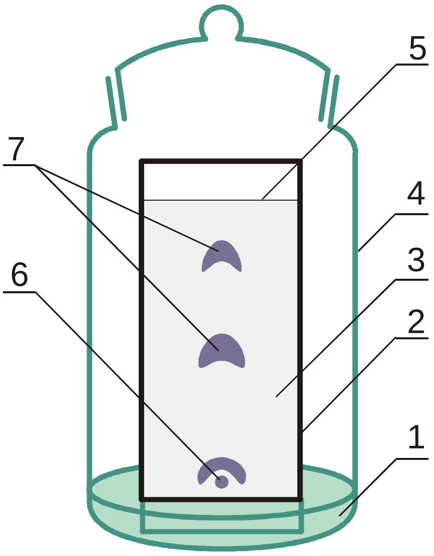
adsorb	zaadsorbować
adsorbent	adsorbent
alumina	tlenek glinu
amino acid	aminokwas
chromatogram	chromatogram
column chromatography	chromatografia kolumnowa
develop	rozwijać, wywołać
dip	zanurzyć, zamoczyć
elute	wymywać

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 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

11.2.3. *Exercises*

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

1	
2	
3	
4	
5	
6	
7	



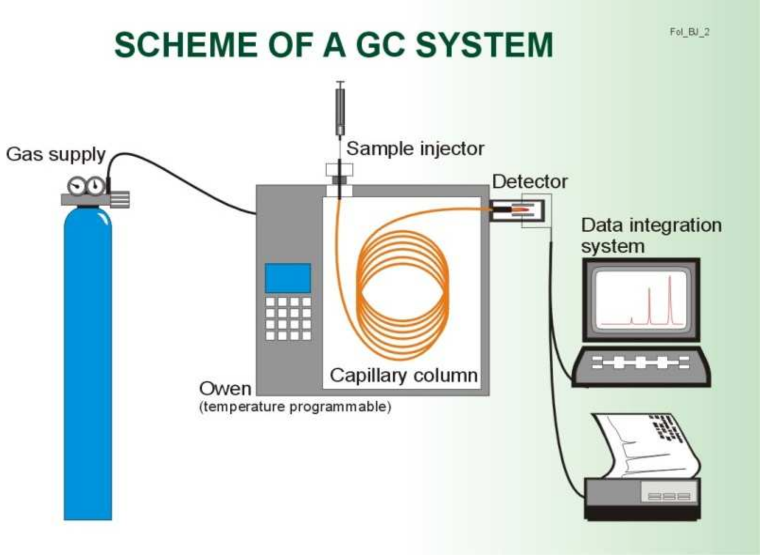
2. Fill in the blanks.

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 ....

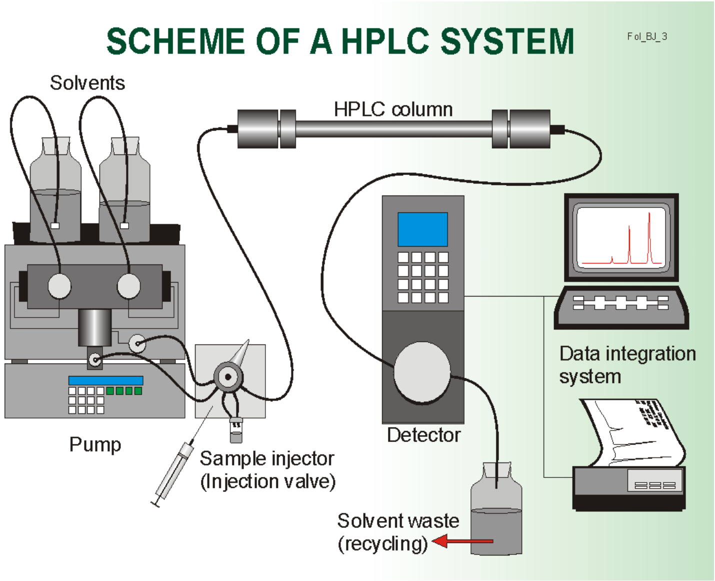
11.3. Instrumental laboratory techniques

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.



11.3.1. *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?

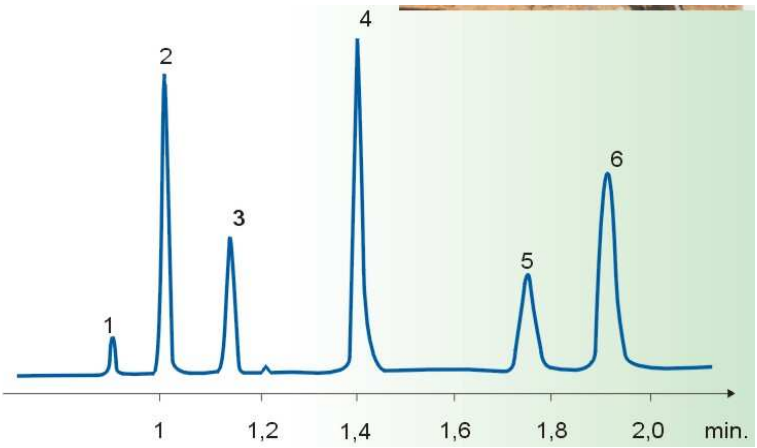
11.3.2. *New terms and expressions*

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

11.3.3. *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.

12. Spectroscopy. Part I.

12.1. Principles of spectroscopy

The energy of matter is quantized at the microscopic level. This means that a particle (electron, atom, molecule, etc.) can take only certain, specific values of energy, referred to as energy states or energy levels. If the particle is in one energy state, say E_1, and it absorbs some energy, it is excited to the higher energy state E_2. This transition occurs only when the portion of absorbed energy matches exactly the difference between the two energy states. This observation provides the general foundation for a group of instrumental techniques known as spectroscopic methods.

In spectroscopy, a sample is subjected to electromagnetic radiation of a specific energy range. Then, the radiation that has passed through the sample is analysed for any wavelengths absorbed during this process. The result usually takes the form of a graph showing how the magnitude of absorption varies with the wavelength (or frequency, or wavenumber); this is referred to as a spectrum.

Definitions:

$\lambda \times \nu = c$; $\Delta E = h \times \nu$; $\bar{u} = \dfrac{1}{\lambda}$

where

ΔE: energy absorbed/emitted

λ: wavelength

ν: frequency

$\bar{u}$: wavenumber

c: speed of light, 3×10^8 m s^{-1}

h: Planck's constant, 6.63×10^{-34} J s

12.1.1. *Reading comprehension*

1. What does it mean that the energy of particles is quantized?
2. Why do particles absorb only specific values of energy?
3. Explain the general concept of spectroscopy.

12.1.2. *New terms and expressions*

absorb	pochłaniać, absorbować
absorption	absorpcja
attenuation	osłabienie
consecutive	kolejny
cycle	okres (drgania), cykl
electromagnetic	elektromagnetyczny
energy level	poziom energetyczny
energy state	stan energetyczny
foundation	podstawa, fundament
frequency	częstotliwość
level	poziom
magnitude	wielkość
match	pasować
particle	cząstka
provide	dostarczać, zapewniać, stanowić
spectroscopy	spektroskopia
spectrum	widmo
subject	poddawać, wystawiać na
transition	przejście
vibration	drganie
wavelength	długość fali
wavenumber	liczba falowa

12.1.3. *Exercise*

1. Give the expressions matching the definitions in the left-hand column.

The constant relating the energy of electromagnetic radiation to its frequency.	
The distance between two consecutive maxima of a wave.	

The graph showing how the absorption of electromagnetic radiation depends on its wavelength.	
The number of full vibration cycles in unit length.	
The number of full vibration cycles in unit time.	
The product of wavelength and frequency.	
The attenuation of radiation intensity as it passes through a sample of matter.	

12.2. UV-VIS spectroscopy

The transition of an electron from the ground to an excited energy level gives rise to the absorption of ultraviolet radiation and sometimes also visible light. Typical UV-VIS spectrometers operate in the 200 – 700 nm range of wavelengths. Absorption spectra usually consist of a few very broad absorption bands, so UV-VIS spectroscopy is rarely used for the determination of molecular structure. On the other hand, absorption is quantitatively related to the concentration of the absorbing species, in accordance with the Beer-Lambert law. For this reason UV-VIS spectrometry is extensively used in colorimetric analysis or in monitoring the course of chemical change.

Beer-Lambert law:

$$A = -\log \frac{I}{I_0} = \varepsilon \times l \times c$$

where

A: absorbance

I: intensity of light that has passed through a sample

I_0: intensity of light before it enters a sample

ε: proportionality constant (molar absorption coefficient) $\mathrm{mol^{-1}\ dm^{-3}\ cm^{-1}}$

l: distance light travels in the solution (path length) cm

c: concentration of the solution (molarity) $\mathrm{mol\ dm^{-3}}$

Origin of colour:
Coloured substances absorb visible light in the 400 – 700 nm range, which requires the electron energy levels to be quite close to one another. This is the case with *d*-electrons, so transition metal compounds are usually coloured owing to the presence of partially occupied *d*-orbitals. Coloured organic compounds usually contain conjugated π systems, in which electrons are delocalized over a large portion of the molecule, as in carotene or azo dyes.

12.2.1. *Reading comprehension*

1. In what wavelength range can electron transitions be studied?
2. What does a typical UV-VIS spectrum look like?
3. Where is UV-VIS spectroscopy most useful?
4. Define the molar absorption coefficient ε.
5. Why are transition metal compounds usually coloured?
6. Which organic compounds absorb visible light?

12.2.2. *New terms and expressions*

absorbance	absorbancja
absorption band	pasmo absorpcyjne
absorption spectrum	widmo absorpcyjne
colorimetry, colorimetric	kolorymetria, kolorymetryczny
cuvette	kiuweta
excited energy level	wzbudzony poziom energetyczny
extensive	powszechny, częsty, rozległy
ground energy level	podstawowy poziom energetyczny
molar absorption coefficient	molowy współczynnik ekstynkcji
operate	działać
path length	długość drogi
proportionality constant	współczynnik proporcjonalności
rare	rzadki, nieczęsty
spectrometer	spektrometr
ultraviolet	nadfioletowy
visible light	światło widzialne

12.2.3. *Exercise*

1. Fill in the blanks.

The UV-VIS spectrum of pink $[Co(H_2O)_6]^{2+}$ ions contains a weak and broad absorption .... in the .... region at 515 nm. It is too weak for .... measurements, so before determination of the Co(II) concentration, some .... ions SCN^- are added to the solution. The spectrum of the resulting blue $[Co(SCN)_4]^{2-}$ complex reveals a much more .... absorption at 625 nm. The .... recorded for a $1.5×10^{-4}$ *M* solution of the cobalt complex shows an absorbance of 0.27 with a cuvette of 1 cm .... length. This means that according to the ....-................................. law, the molar .... of $[Co(SCN)_4]^{2-}$ is 1800. The colour of this complex can be accounted for by the presence of .... in the cobalt(II) ion.

12.3. Infrared (IR) spectrometry.

IR spectrometry typically uses infrared radiation from the 4000 – 400 cm^{-1} (2.5 – 25 μm) range. The absorption of IR is associated with the stretching and bending vibrations of covalent bonds. The position of an absorption band depends on the mass of atoms linked by the bond as well as on the bond strength, so IR spectrometry is particularly suitable for detecting the presence (or absence) of particular functional groups.

Typical absorption ranges are listed in correlation charts, which are very useful when determining the molecular structure of organic compounds. For example, a strong absorption band near 1700 cm^{-1} indicates the presence of a carbonyl group C=O, while the substitution configuration of the benzene ring can be deduced from the pattern of peaks in the 900 – 650 cm^{-1} range.

The long-wave portion of an IR spectrum is called the fingerprint region, since it is unique to a particular compound. Fingerprint regions are used for identifying compounds by comparing recorded spectra with those collected in data bases.

12.3.1. *Reading comprehension*

1. What is an IR absorption band associated with?
2. Where are typical ranges of absorption listed?
3. What functional group could be present if there is a strong absorption band near 1700 cm^{-1} in the IR spectrum?
4. What is a 'fingerprint region'?

12.3.2. *New terms and expressions*

bending vibrations	drgania zginające
bond strength	siła wiązania
configuration	układ, konfiguracja
correlation chart	tablica wiążąca cechę widma ze strukturą cząsteczki
data base	baza danych
fingerprint	odcisk palca
infrared	podczerwień, podczerwony
long-wave	długofalowy
mode	sposób
pattern	wzór, układ
stretching vibrations	drgania rozciągające
suitable	odpowiedni, właściwy

12.3.3. *Exercise*

1. Indicate which statements are true (T) and which are false (F).

a. IR is electromagnetic radiation of shorter wavelength than UV. T / F

b. In the stretching vibration mode, the bond length changes periodically but the bond angle remains the same. T / F

c. In an IR spectrum, the $C{\equiv}C$ group gives rise to an absorption band at a longer wavelength than the $C{=}C$ one does. T / F

d. In the IR spectrum, the $C{=}O$ group gives rise to an absorption band at a higher wavenumber than the $C{=}S$ one does. T / F

e. All compounds showing a prominent absorption peak near 1700 cm^{-1} should give a positive result in Brady's test. T / F

f. The typical wavenumber range of the fingerprint region is 4000 – 2000 cm^{-1}. T / F

g. Comparison of a recorded IR spectrum with one found in a spectroscopic data base enables a molecular structure to be fully determined. T / F

13. Spectroscopy. Part II.

13.1. Nuclear magnetic resonance (NMR) spectroscopy.

Many atomic nuclei posses a nuclear spin, which makes them behave like tiny magnets. When a strong magnetic field is applied, they tend to align either with the direction of the field or against it. These two orientations have slightly different energies, so the transition between them involves the absorption of electromagnetic radiation. Even in the strongest magnetic fields attained by modern superconducting magnets, the splitting of energy levels is quite small and the absorbed radiation falls in the range of long-wave radiowaves (50 – 200 cm).

The absorption of radiowaves by a sample placed in a strong magnetic field is called nuclear magnetic resonance (NMR). This phenomenon is used in NMR spectroscopy. Modern spectrometers detect changes in absorption caused by very subtle variations of the magnetic field. The result, plotted as an NMR spectrum, reveals many details about the structure of the molecules studied.

Today, NMR spectroscopy is an invaluable tool for the determination of molecular structures. ^{1}H and ^{13}C nuclei are most commonly used in NMR experiments, although studying the resonance of other nuclei is possible as well. A typical proton NMR spectrum contains a number of signals, each corresponding to a group of equivalent hydrogen atoms. Very often, the signals are split into multiplets (e.g. doublets, triplets, quartets) as a result of coupling between the nuclei of non-equivalent atoms. Additional information is provided by the integration of NMR signals that gives clues as to the number of particular hydrogen atoms present in the molecule. By examining the chemical shifts of the signals, their splitting pattern and intensity, one can deduce the overall structure of the compound.

Modern techniques, such as decoupling experiments and two-dimensional correlation spectroscopy, make it possible to study the structures of even highly complex biomolecules such as proteins, saccharides or nucleotides.

Proton magnetic resonance is also employed in diagnostic medicine. When the human body is placed in a strong magnetic field, resonating hydrogen nuclei form a three-dimensional image of the internal organs. This tomographic technique is referred to as magnetic resonance imaging (MRI).

13.1.1. *Reading comprehension*

1. What is the origin of the energy level splitting in magnetic resonance?
2. What range of electromagnetic radiation is used in NMR spectroscopy?
3. Which nuclei are most commonly used in NMR spectroscopy?
4. Why are NMR absorption signals often split into multiplets?
5. What can you deduce from the integration of NMR signals?
6. What is the general idea of magnetic resonance imaging?

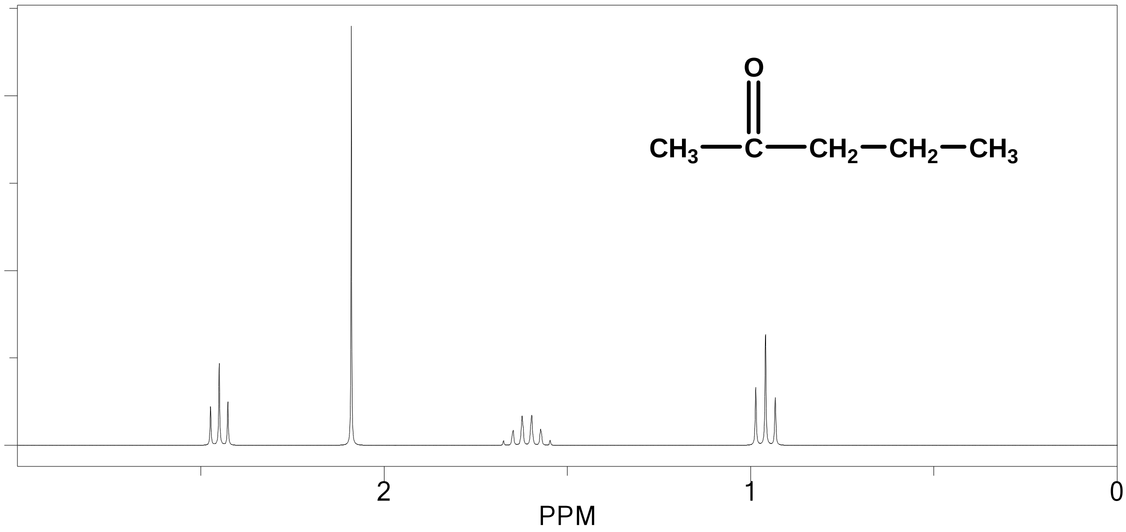
13.1.2. *New terms and expressions*

against	przeciw
align	ułożyć się
attain	osiągać
chemical shift	przesunięcie chemiczne
correlation	korelacja
coupling	sprzężenie
decoupling	rozprzęganie (podwójny rezonans)
diagnostic	diagnostyczny
direction	kierunek
doublet, triplet, quartet, ...	dublet, tryplet, kwartet, ...
equivalent	równocenny
employ	wykorzystywać, używać
image	wizerunek, obraz
integration	całkowanie
intensity	intensywność
invaluable	bezcenny
magnet	magnes
magnetic field	pole magnetyczne
magnetic nuclear resonance	magnetyczny rezonans jądrowy
magnetic resonance imaging	obrazowanie rezonansu magnetycznego
multiplet	multiplet
nuclear spin	spin jądrowy
nucleotide	nukleotyd
orientation	orientacja (w przestrzeni)

phenomenon	zjawisko
plot	wykreślać, rysować
protein	białko
radiowave	fala radiowa
saccharide	węglowodan
signal	sygnał, pik, pasmo
split	rozszczepiać
subtle	subtelny
superconducting magnet	magnes nadprzewodzący
tiny	malutki, niewielki
tomography	tomografia
two-dimensional	dwuwymiarowy

13.1.3. *Exercise*

1. Examine the proton NMR spectrum of pentan-2-one. Assign all the resonances to the relevant groups of hydrogen atoms.



The spectrum contains .... absorption signals. Each signal corresponds to a different group of .... hydrogen atoms. .... of the signals gives the .... ratio of 2:3:2:3 (from left to right). The .... group attached directly to the carbonyl carbon atom gives rise to a sharp .... at 2.1 ppm. The signal due to the methylene group on the other side of carbonyl carbon atom has an even higher .... of 2.4 ppm. This is a .... due to coupling with the neighbouring .... group. We can observe the same coupling .... for the other .... group, producing a triplet at 0.9 ppm. The remaining methylene group is .... to as many as .... hydrogen neighbours, so the resulting signal at 1.6 ppm is composed of .... components.

13.2. Mass spectrometry (MS)

Moving electrically charged particles are deflected from their path by a magnetic field. This phenomenon is exploited by mass spectrometry, a technique widely used in the determination of molecular structure.

Molecules are first ionized, for example by bombardment with high energy electrons. The resulting positive ions are accelerated in the mass spectrometer and deflected by a magnetic field. The angle of deflection depends on the charge and mass of the particle. Since most of the ions produced in the ionization chamber posses a +1 charge, the magnetic field separates them according to their mass. As a result, a mass spectrum is produced. The spectrum consists of many narrow peaks, each of them representing an ion of different mass. The height of the peak represents the ion’s abundance.

Examination of the molecular ion peaks in the spectrum gives direct information about the molecular mass of the compound. Moreover, fragmentation ions and isotope ions provide additional clues about the actual structure of the molecule.

13.2.1. *Reading comprehension*

1. How does a magnetic field interact with moving charged particles?
2. How are neutral molecules ionized in a mass spectrometer?
3. What does a mass spectrum look like?
4. What information is provided by mass spectra?

13.2.2. *New terms and expressions*

abundance	rozpowszechnienie (udział procentowy)
accelerate	przyspieszać
bombardment	bombardowanie
deflect	odchylać
fragmentation ion	jon fragmentacyjny
ionization chamber	komora jonizacyjna
ionize	jonizować
mass spectrometry	spektrometria masowa
molecular ion (peak)	jon (pik) molekularny
path	droga, ścieżka, tor

13.2.3. *Exercise*

1. Match the expressions

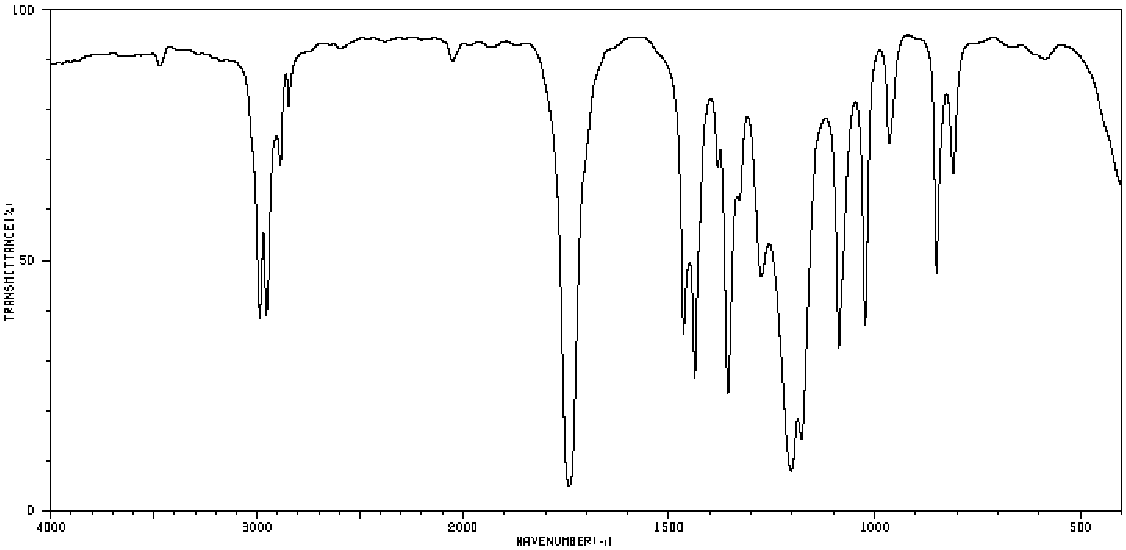
To change the direction of moving particles.	abundance
To force a particle to move faster.	accelerate
An ion having the same molecular mass as the initial molecule.	bombarding with electrons
An ion produced by the breakup of the initial molecule.	deflect
The line along which a particle travels.	fragmentation ion
One of the methods of ionization.	ionize
The percentage of one type of particles among all others.	molecular ion
To convert molecules to ions.	path

13.3. Determination of molecular structure: an example.

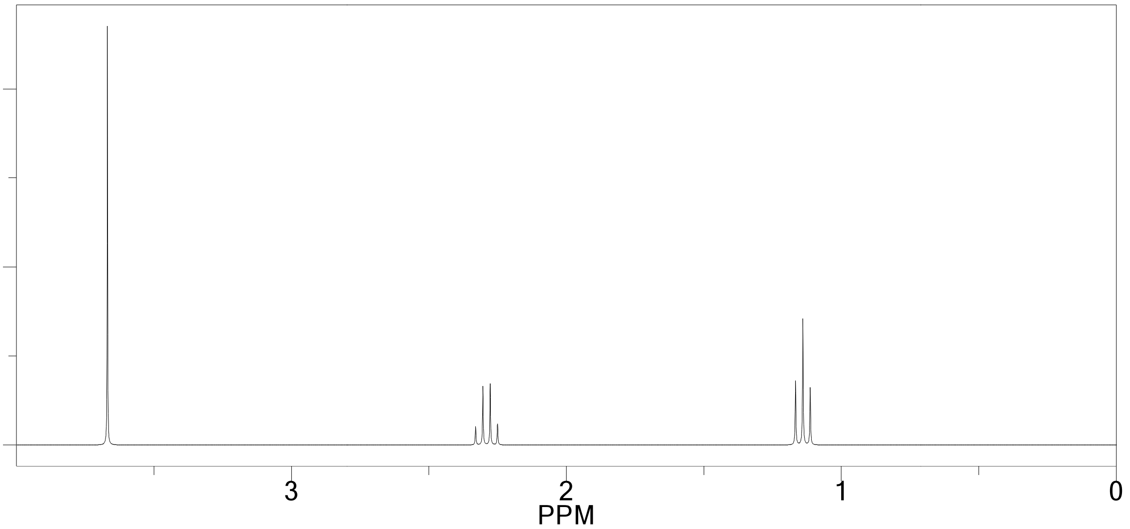
13.3.1. *Analytical data:*

Empirical formula (from elemental analysis)	C_2H_4O
Appearance	colourless liquid, distinct smell
Solubility in water	insoluble, pH of an aqueous suspension about 7
Bromine water test	negative (no discolouration)
Brady's test	negative (no orange precipitate)

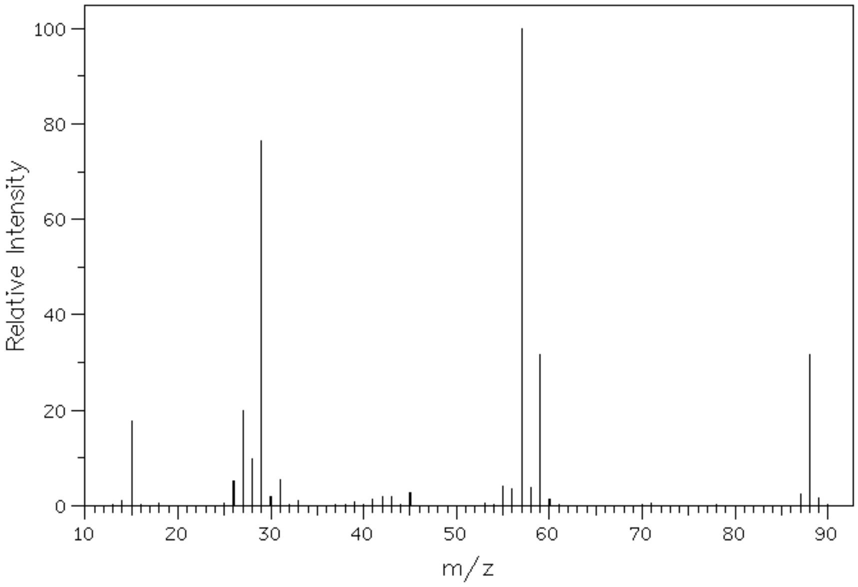
13.3.2. *IR spectrum:*



13.3.3. *Proton NMR spectrum:*



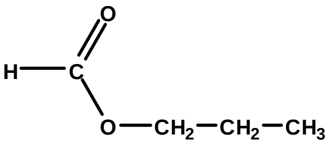
13.3.4. *Mass spectrum:*



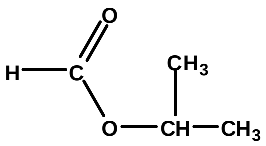
13.3.5. *Structure determination:*

1. The empirical formula C_2H_4O accounts for a relative mass of 44. No peak corresponding to this mass is seen in the mass spectrum. However, a quite prominent peak at *m/z* = 88 (double the mass of the empirical formula) indicates that the molecular formula of the compound is $C_4H_8O_2$.
2. The hydrogen deficiency index is $4 - ½ \times 8 + 1 = 1$, which means that there is either one double bond or one closed ring in the molecule. Since a C=C bond is excluded by the bromine water test, the potential double bond must be a C=O bond.
3. A distinct, strong absorption band in the IR spectrum (near 1740 cm^{-1}) confirms the presence of a carbonyl group in the molecule, so the hydrogen deficiency index 1 results from the C=O bond.
4. Brady's test excludes the presence of an aldehyde or a ketone. The neutral pH of the aqueous suspension and the absence of a strong, broad band at about 3000 cm^{-1} (typical of O-H stretching in a carboxylic acid) exclude the presence of acids. So compound A must be an ester.

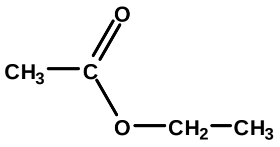
5. There are four possible structures of esters with the molecular formula $C_4H_8O_2$:



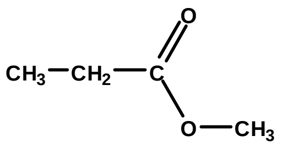
I



II



III



IV

6. The proton NMR spectrum shows three absorption signals, which means that there are three different groups of equivalent hydrogen atoms in the molecule. This immediately excludes structure I, for which four separate signals could be predicted.
7. From integration, the intensity ratio of the NMR signals is 3:2:3. This means that there are two groups of three hydrogen atoms (CH_3) and one group of two hydrogen atoms (CH_2) in the molecule. This in turn excludes structure II, for which the intensity ratio 1:1:6 should be expected.
8. From the splitting pattern, we see that one CH_3 group is isolated (a singlet at 3.67 ppm), while the other CH_3 group is coupled to a CH_2 group (a set of quartets at 2.29 ppm and a triplet at 1.14 ppm). This is consistent with both structures III and IV.
9. Examining the correlation chart for methyl groups in esters:

   CH_3–C(O)–O– $\delta = 2.1 – 2.3$ ppm

   –C(O)–O–**CH_3** $\delta = 3.4 – 3.8$ ppm

   immediately shows us that the compound A is in fact methyl propanoate (IV).
10. The intense peak at *m/z* = 57 in the mass spectrum, corresponding to the acylium fragmentation ion $CH_3CH_2CO^+$, confirms this structure.

13.3.6. *Reading comprehension*

1. How was the molecular mass of A found?
2. How did we arrive at the conclusion that A is an ester?
3. Why could we exclude structures I and II using NMR spectra?
4. How was it possible to distinguish between structures III and IV, even though both should produce the same splitting pattern?
5. What confirmation for structure IV can we find in the mass spectrum?

13.3.7. *New terms and expressions*

acylium ion	jon (kation) acyliowy
consistent	zgodny, spójny
distinct	wyraźny, wyrazisty
elemental analysis	analiza elementarna
exclude	wykluczać, wyłączać
expect	oczekiwać, spodziewać się
hydrogen deficiency index	stopień nienasycenia
potential	możliwy, potencjalny, ewentualny
predict	przewidywać
prominent	wybitny, wyróżniający się
reference	wzorzec, odnośnik
separate	osobny, oddzielny
suspension	zawiesina

13.3.8. *Exercise*

1. Which statements are true (T) and which are false (F)?

a. For structure I:

- the NMR spectrum would contain two triplets and two quartets T / F
- the MS would contain a prominent acylium ion peak at *m/z* = 43. T / F

b. IR spectra of carboxylic acids:

- do not contain a strong absorption band near 1700 cm^{-1} T / F
- contain a strong, broad absorption band near 3000 cm^{-1}. T / F

c. Cyclohexanol contains six different sets of equivalent hydrogen atoms T / F

d. For the isopropyl group, a set of doublets and a septet of intensity ratio 6:1 is seen in the proton NMR spectrum. T / F

e. Among the isomeric dinitrobenzenes, only 1,2-dinitrobenzene produces a singlet in the proton NMR spectrum. T / F

f. A molecular or fragmentation ion composed of two peaks of equal height and separated by two *m/z* units suggests the presence of bromine. T / F

g. In alcohols, the hydroxyl hydrogen atom is always coupled to neighbouring hydrogen atoms. T / F

h. Tetramethylsilane is the most common reference used in NMR spectroscopy. T / F

14. Basic Concepts in Physical Chemistry. Part I.

14.1. Enthalpy

Physical and chemical changes are usually accompanied by energy transfer to or from the surroundings. Energy may be exchanged with the surroundings in two forms: work or heat. Thermochemistry is the branch of chemistry that studies the heat changes of chemical reactions, while thermodynamics is the science dealing with energy-heat-work conversions in more general terms.

Enthalpy is the thermodynamic property of matter that describes the capacity of the system to release heat. Absolute values of enthalpy H cannot be determined. Only enthalpy changes ΔH can be measured experimentally as the heat exchanged with the surroundings under constant pressure. In exothermic processes, heat is released to the surroundings, so the enthalpy of the system decreases and the enthalpy change has a negative sign ($\Delta H < 0$). Conversely, in endothermic processes heat is absorbed from the surroundings, the enthalpy of the system increases, and the enthalpy change is positive ($\Delta H > 0$).

Enthalpy changes are determined by a technique known as calorimetry. For example, enthalpies of combustion are measured in a bomb calorimeter, in which a known amount of a substance is burned in oxygen and the resulting temperature change gives clues to the actual amount of heat released.

Standard enthalpy changes, i.e. enthalpy changes under standard conditions (pressure 100 kPa, temperature usually 298 K, all reagents in their standard states), are listed in data bases. The most important of these quantities is the standard enthalpy of formation. Enthalpy is a state function, so if we know the standard enthalpies of formation for all reagents, we can compute the standard enthalpy change for any reaction using Hess's law of constant heat summation. Hess's law is a direct consequence of the first law of thermodynamics:

First law of thermodynamics (principle of conservation of energy):

Energy can be neither created nor destroyed. Energy can only change its form. The sum total of energy in the universe is constant.

14.1.1. *Reading comprehension*

1. What are the two forms of energy transfer between a system and its surroundings?
2. What is the difference between thermodynamics and thermochemistry?
3. Define the term ‘exothermic process’.
4. What technique is used to determine enthalpy changes?
5. What is a standard enthalpy change?
6. What does the first law of thermodynamics state?

14.1.2. *New terms and expressions*

absolute	bezwzględny
atomization	atomizacja
bomb calorimeter	bomba kalorymetryczna
calorimetry	kalorymetria
capacity	zdolność, pojemność
change (chemical, physical)	przemiana (chemiczna, fizyczna)
compute	obliczyć
concept	koncepcja, pojęcie
consequence	konsekwencja, skutek
conversely	na odwrót, przeciwnie
conversion	przemiana, przekształcenie
create	stworzyć
deal with	mieć do czynienia z
destroy	zniszczyć
endothermic	endotermiczny
energy transfer	przepływ energii
enthalpy of combustion	entalpia spalania
enthalpy of formation	entalpia tworzenia
exothermic	egzotermiczny
first law of thermodynamics	pierwsza zasada termodynamiki
fusion	stopienie
heat	ciepło
lattice enthalpy	entalpia (energia) sieci
principle of conservation of energy	zasada zachowania energii

release	uwolnić, wydzielić
standard conditions	warunki standardowe
standard state	stan standardowy
state function	funkcja stanu
surroundings	otoczenie
system	układ, system
thermodynamics, thermodynamic	termodynamika, termodynamiczny
thermochemistry	termochemia
Universe	Wszechświat
vapourization	odparowanie
work	praca

14.1.3. *Exercises*

1. Match the types of standard enthalpy changes with their definitions.

The enthalpy change taking place when 1 mole of a substance in its standard state:

is formed as a ionic crystal from individual ions in the gaseous state at 100 kPa and 298 K	standard enthalpy of formation
is converted completely to individual atoms in the gaseous state at 100 kPa and 298 K	standard enthalpy of combustion
is burned in excess oxygen at 100 kPa and 298 K.	standard enthalpy of fusion
is formed from the elements in their standard states at 100 kPa and 298 K.	standard enthalpy of vapourization
is converted from its solid to its liquid form at 100 kPa	standard enthalpy of sublimation
is dissolved in excess solvent at 100 kPa and 298 K	standard enthalpy of solution
is converted from a solid to a vapour at 100 kPa	standard enthalpy of atomization
is converted from a liquid to a vapour at 100 kPa	lattice enthalpy

14.2. Entropy and free energy

Entropy is a state function that represents the degree of disorder in the system. Entropy tells us in how many ways a set of particles in the system (or in the surroundings) can be arranged and in how many ways energy can be distributed among them. For example, an ionic crystal is a highly ordered system, since every ion has a specific position in a crystal lattice and it may possess vibrational energy in rather a narrow range. Therefore, the entropy S of a crystalline solid is usually low. On the other hand, a gas is a highly disordered system, since particles move freely in the container and may possess kinetic energy over quite a broad range. Consequently, gases are characterized by very high entropy values.

The second law of thermodynamics states that a physical or chemical change is spontaneous only when the total entropy of the system and the surroundings increases ($\Delta S_{total} > 0$). Since the entropy change of the surroundings ΔS_{surr} is proportional to the enthalpy change ΔH of the system and to the temperature T, the condition for the spontaneity of change takes the following form:

$$\Delta G = \Delta H - T\Delta S < 0 \qquad (1)$$

where ΔG is termed the change in free energy or Gibbs' free energy. For a spontaneous change, the free energy change must be negative ($\Delta G < 0$). Equation (1) explains why exothermic reactions (with $\Delta H < 0$) are usually spontaneous and why some endothermic reactions that are not spontaneous at low temperature may become spontaneous at a sufficiently high temperature (just consider what happens to the term $T\Delta S$ when the temperature rises).

Second law of thermodynamics:

Spontaneous natural processes increase the overall entropy of the universe.

14.2.1. *Reading comprehension*

1. Give the definition of entropy.
2. Which system has a higher entropy: liquid water or solid ice?
3. Why are gases characterized by exceptionally high entropies?
4. What is the fundamental condition for a process to be spontaneous?
5. Why are exothermic reactions usually spontaneous?

14.2.2. *New terms and expression*

arrange	ułożyć, uporządkować
assume (take)	przyjąć
become	stać się
broad	szeroki
consider	rozważać
container	zbiornik, naczynie
degree	stopień
disorder, disordered	nieuporządkowanie, nieuporządkowany
distribute	rozdzielić
entropy	entropia
free energy, Gibbs' free energy	energia (entalpia) swobodna, energia swobodna Gibbsa
kinetic energy	energia kinetyczna
lattice	sieć (krystaliczna)
narrow	wąski
order, ordered	uporządkowanie, uporządkować
overall	całkowity
proportional	proporcjonalny
second law of thermodynamics	druga zasada termodynamiki
spontaneity	spontaniczność, samorzutność
spontaneous	spontaniczny, samorzutny
sufficiently	odpowiednio
vibrational	związany z drganiami, wibracyjny

14.2.3. *Exercises*

1. Fill in the blanks.

The standard .... (ΔH^0) for the decomposition of calcium carbonate:

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

is +178 kJ mol^{-1}. This means that the reaction is .... The standard .... change for this reaction (ΔS^0) is +161 J $K^{-1}mol^{-1}$. This value is large and ...., since one of the products is a .... After the reaction, the system is much more .... than before it. At .... (25^{o}C), the .... change of the reaction (ΔG) is +130 kJ mol^{-1}. At this temperature, the decomposition of calcium carbonate is .... and the salt is perfectly stable. The .... reaction, the absorption of .... by calcium .... is .... At 1000^{o}C though, ΔG = –27 kJ mol^{-1} and the reaction becomes .... This explains why the decomposition of calcium .... requires .... at high ....

2. Give the appropriate term or phrase.

a form of energy transfer other than work	
heat transfer that occurs at constant pressure	
a function that describes the degree of disorder of the system	
a reaction as a result of which energy is evolved	
a function that describes the capacity of a process to run spontaneously	
a process for which $\Delta G > 0$	
a process for which $\Delta H > 0$	

15. Basic Concepts in Physical Chemistry. Part II.

15.1. Chemical equilibrium

A pink solution of cobalt(II) chloride $CoCl_2$ in dilute hydrochloric acid HCl contains $[Co(H_2O)_6]^{2+}$ complex ions. When the solution is heated, it turns blue owing to the formation of $[CoCl_4]^{2-}$ ions – these have a different geometry. If, in turn, the hot solution is allowed to cool down, the pink colour reappears. This means that the reaction

$$\underset{\text{pink}}{[Co(H_2O)_6]^{2+}(aq)} + 4\,Cl^-(aq) \rightleftharpoons \underset{\text{blue}}{[CoCl_4]^{2-}(aq)} + 6\,H_2O(l)$$

is reversible. At high temperatures the forward reaction occurs (from left to right), while at low temperature the reverse reaction takes place. The reversibility of the reaction is indicated by the sign'$\rightleftharpoons$' (two arrows).

Many reversible reactions run forwards and backwards at the same time. In this case, neither the forward nor the reverse reaction goes to completion. Instead, a state of dynamic equilibrium is reached where the overall concentrations of reactants and products do not change over time. In a state of dynamic equilibrium, the rates of the forward and reverse reactions are exactly the same, so on a macroscopic scale the concentrations do not change.

Chemical equilibrium is characterized by the equilibrium constant K_c. For the reaction

$$aA + bB \rightleftharpoons cC + dD$$

it is defined as

$$K_c = \frac{[C]^c\,[D]^d}{[A]^a\,[B]^b}$$

where [C] and [D] are the concentrations (molarities) of the products, [A] and [B] are the concentrations of the reactants, and *a*, *b*, *c*, *d* are stoichiometric coefficients. Very large values of K_c indicate that the forward reaction is strongly favoured and that the reaction is practically irreversible. On the other hand, very low K_c values mean that the reverse reaction is practically irreversible. If values of K_c are intermediate, an equilibrium mixture is formed that contains both reactants and products.

Chemical equilibrium may be affected by the concentrations of reagents, pressure (for reactions taking place in the gaseous phase) and temperature, in accordance with Le Chatelier's principle. Using an excess of reactants and removing the reaction products favours the forward reaction. Increasing the pressure favours reactions occurring in the gaseous phase, where the overall volume of products is smaller than the volume of reactants. In endothermic reactions, a high temperature shifts the equilibrium towards the products, whereas in exothermic reactions the effect is the opposite. Knowing the effects of concentration, pressure and temperature on chemical equilibrium helps to maximize the yield of a desired product of reversible reactions.

15.1.1. *Reading comprehension*

1. Describe the behaviour of a cobalt(II) chloride – hydrochloric acid solution on being heated and cooled.
2. What kinds of reaction are reversible?
3. How do we indicate that a reaction is reversible?
4. Define the equilibrium constant.
5. What is the significance of a very low value of K_c?
6. How does concentration affect chemical equilibrium?
7. How does temperature affect chemical equilibrium?

15.1.2. *New terms and expressions*

accomplish	osiągnąć
affect	mieć wpływ
allow	pozwolić
arrow	strzałka
backwards	do tyłu
catalyst	katalizator
character	znak drukarski
characterize	charakteryzować
chemical equilibrium	równowaga chemiczna
coefficient	współczynnik
completion	koniec, stan całkowitego przereagowania

desired	pożądany
dilute (solution)	(roztwór) rozcieńczony
dynamic equilibrium	równowaga dynamiczna
effect	wpływ
equilibrium (equilibria)	równowaga (równowagi)
equilibrium constant	stała (równowagi) reakcji
equilibrium mixture	mieszanina równowagowa
excess	nadmiar
favour (US favor)	sprzyjać
forwards	do przodu
forward reaction	reakcja w takim kierunku, jaki przedstawia równanie chemiczne (‘do przodu’)
irreversible reaction	reakcja nieodwracalna
Le Chatelier's principle	reguła przekory Le Chateliera
macroscopic	makroskopowy
maximize	zwiększać, maksymalizować
moderate	umiarkowany
molarity	stężenie molowe
plunger	tłok (np. strzykawki)
product	produkt
rate (reaction rate)	szybkość (szybkość reakcji)
reactant	substrat
reagent	reagent
reappear	pojawić się ponownie
removal	usuwanie
reverse reaction	reakcja w kierunku przeciwnym do tego, który przedstawia równanie chemiczne, reakcja odwrotna.
reversibility	odwracalność
reversible reaction	reakcja odwracalna
stoichiometric	stechiometryczny
turn blue / pink	zmienić kolor na niebieski/różowy

15.1.3. *Exercises*

1. Indicate which statements are true (T) and which are false (F).

a.	In a state of chemical equilibrium, neither the forward nor the reverse reaction occurs.	T / F
b.	A very small value of K_c indicates that the forward reaction practically does not occur.	T / F
c.	Increasing the temperature of an exothermic reaction shifts the equilibrium towards the products.	T / F
d.	Using an excess of reactant is a common way of increasing yields of products in reversible reactions.	T / F
e.	The esterification of a carboxylic acid with an alcohol is a well-known example of an irreversible reaction.	T / F
f.	The position of chemical equilibrium is strongly affected by catalysts.	T / F

2. Brown nitrogen dioxide NO_2 exists in equilibrium with the colourless dimer dinitrogen tetroxide N_2O_4, according to the following thermochemical equation:

$$2\,NO_2(g) \rightleftharpoons N_2O_4(g) \quad \Delta H^o = -58\ \text{kJ mol}^{-1}$$

A glass cylinder contains an equilibrium mixture of both gases at 25°C, closed at the top by a movable plunger. Which of the following actions will darken the colour of the gas mixture, and which will have the opposite effect?

	Action	Colour
a.	Forcefully depressing the plunger.	darker / lighter
b.	Withdrawing the plunger.	darker / lighter
c.	Placing the cylinder in a mixture of water and ice.	darker / lighter
d.	Placing the cylinder in a boiling-water bath.	darker / lighter

15.2. Reaction kinetics

Some reactions are extremely fast. Explosives detonate almost instantaneously, producing huge amounts of gases in a fraction of a second. On the other hand, some reactions are extremely slow. The radioactive decay of the uranium-238 isotope is so slow (half-life = 4.5 billion years) that we can still find useful amounts of this element in the Earth's crust. Again, some reactions, particularly biochemical ones, occur at a carefully controlled rate, which enables living organisms to function properly.

The rate of a reaction is very important from the economic point of view. When trying to minimize costs, people usually want to accelerate desirable processes and to retard or stop harmful ones. The branch of chemistry dealing with reaction rates is called ‘kinetics’.

Collision theory requires that reacting molecules must collide with one another to form the reaction product. That is why most reactions occur in the gaseous or liquid phase, as only then are molecules free to move. The reaction rate is proportional to the number of collisions in unit time. Nevertheless, only a very tiny fraction of all collisions are effective.

In order to form a reaction product or products, molecules must assume a particular orientation with respect to one another. Since only one such orientation is possible and we can think of thousands of other orientations that are ineffective, the probability of finding the ‘right’ orientation is quite low, and only a few collisions result in a chemical reaction. Another limitation comes from the consideration of energy requirements. Molecules are surrounded by electrons that form a kind of fuzzy, negatively charged cloud around them. As two molecules approach one another, the repulsion between the electron clouds start to grow. Only when the combined kinetic energies of the molecules overcome this intermolecular repulsion can the electrons be rearranged and new bonds formed. This minimum energy required for the reaction to occur is called the activation energy. If the kinetic energy of the colliding molecules is lower than the activation energy, the collisions are ineffective.

The rate of reaction is affected by the concentration of reactants, temperature and catalysts. Increasing the concentration of the reactants increases the reaction rate, since there are more molecules per unit volume and the collisions between them become more frequent. Temperature affects the Maxwell-Boltzmann distribution of kinetic energy among the molecules, so at a higher temperature more molecules posses a kinetic energy exceeding the activation energy, and the reaction rate increases. Catalysts are substances that lower the activation energy by offering an alternative mechanism for the reaction. This again leads to a larger number of molecules with an energy exceeding the new, lower activation energy, more collisions become effective and the reaction rate increases. An inhibitor is a kind of ‘negative’ catalyst that increases the activation energy and slows down the reaction. Both catalysts and inhibitors are important chemicals in many practical applications. For example, nickel is a commonly used catalyst in the hydrogenation of unsaturated fats, and ascorbic acid (vitamin C) is a food additive preventing undesirable oxidation reactions.

15.2.1. *Reading comprehension*

1. Give examples of very fast and very slow reactions.
2. Why must the rate of biochemical reactions be carefully controlled?
3. What is the basic statement of collision theory?
4. How does the orientation of molecules affect the effectiveness of collisions?
5. How does the kinetic energy of molecules affect the effectiveness of collisions?
6. Why does the reaction rate increase with increasing reactant concentration?
7. How does temperature affect the rate of reaction?
8. What are catalysts?

15.2.2. *New terms and expressions*

activation energy	energia aktywacji
additive	substancja dodana
billion	miliard
catalyst	katalizator
collide	zderzać (się)
collision theory	teoria zderzeń (aktywnych)
consideration	rozważanie
crust	skorupa
desirable	pożądany

detonate	wybuchnąć
enhance	zwiększyć
exceed	przekraczać, przewyższać
explosive	materiał wybuchowy
fuzzy	rozmyty, mglisty
hydrogenation	uwodornienie
ineffective	nieefektywny
inhibitor	inhibitor
intermolecular	międzycząsteczkowy
joint	łączny
kinetic energy	energia kinetyczna
kinetics	kinetyka
limitation	ograniczenie
Maxwell-Boltzmann distribution	rozkład Maxwella-Boltzmanna
mechanism	mechanizm
minimize	zminimalizować
orientation	orientacja, ułożenie
prevent	zapobiegać
probability	prawdopodobieństwo
radioactive decay	rozpad radioaktywny
rate	szybkość (reakcji)
rearrange	przegrupować, ułożyć na nowo
undesirable	niepożądany
unsaturated	nienasycony

15.2.3. *Exercises*

1. Give expressions that match the following definitions.

The branch of chemistry studying the speed at which chemical processes occur.	
A commonly accepted theory explaining at the microscopic level how chemical reactions take place.	
A factor that affects the Maxwell-Boltzmann distribution of energy among molecules and hence the reaction rate.	
The particular way in which a reaction occurs.	
The transformation of one isotope to another by the emission of radiation.	
The speed at which a chemical change occurs.	
A substance capable of lowering the activation energy of a reaction.	
A substance that decomposes rapidly to produce a large amount of gases.	
A substance that prevents undesirable processes from occurring.	
The minimum energy necessary to overcome intermolecular repulsion.	
The mutual orientation of colliding molecules that results in a chemical reaction.	

2. Fill in the blanks

Ammonia is synthesized on an industrial scale by the reaction of gaseous .... and .... in the presence of an iron ...., according to the following .... equation:

$$N_2(g) + 3\,H_2(g) \overset{Fe}{\rightleftharpoons} 2\,NH_3(g) \quad \Delta H^o = -92\ \mathrm{kJ\ mol^{-1}}$$

The reaction is ....thermic, so at higher temperatures the yield of the product is .... Unfortunately, at room temperature the reaction is very ...., so it is carried out at 500°C in order to increase the .... To compensate for the yield loss caused by the high temperature, an extremely high .... of about 250 atm is used. Iron .... the .... energy for this reaction. After passing through the reaction chamber, the mixture of gases is .... down to -50°C. Ammonia is liquid at this temperature, since its .... is -33°C, and it can be readily removed. Removing the reaction .... additionally shifts the .... to the ....

16. Pollution and Purification of Water

16.1. Water: circulation and resources

All life forms on Earth depend on water. An average human being needs to consume several litres of freshwater per day to sustain life. Today, about 10% of the human population is experiencing a scarcity of water, but this figure is expected to rise to 38% by 2025. Water resources are an essential component of the Earth's hydrosphere and an indispensable part of all terrestrial ecosystems.

Water circulates throughout Earth's environment by means of the solar-powered hydrologic cycle. Water enters the atmosphere by evaporation of liquid water, the transpiration of plants and the sublimation of solid water (snow, ice). In the atmosphere, it is present as vapour (measured as humidity) and as suspended droplets of liquid water or particles of ice. The relative humidity of air is defined as the ratio (expressed as a percentage) of the partial pressure of water vapour at a particular temperature to the saturated vapour pressure at that temperature. When water molecules leave the vapour phase to form liquid water or ice, condensation begins.

The total global amount of water is 1.4 billion cubic metres, of which nearly 98% is present as saline (salt) water in seas and oceans, which is unsuitable for drinking and for most agricultural purposes. The remaining amount is freshwater; only 13% of this is liquid, while the rest is trapped as snow, snowpack, ice and glaciers. The vast majority of liquid freshwater is located beneath the Earth's surface as groundwater. This is stored below the surface in porous rock formations referred to as aquifers. Bodies of freshwater include lakes, ponds and reservoirs. Water flows from higher altitudes down to the seas and oceans in rivers and streams.

Today, lakes and rivers are one of the main sources of drinking water, although they constitute less than 0.1% of the total water resources. Water is the cheapest and most universally available raw material. Currently, the major global uses of water are as cooling water in electrical power generation and for irrigation in agriculture. Some industrial processes consume vast amounts of water: e.g. 8000 litres of water are needed to produce 1 kg of aluminium, and as many as 400 000 litres to manufacture 1 (one!) car.

16.1.1. *Reading comprehension*

1. Why is water so essential to humankind?
2. What is the driving force behind the water cycle?
3. What are the forms of water in the atmosphere?
4. Why are the majority of global water resources unsuitable for drinking?
5. Name the solid forms of freshwater.
6. Give the names of freshwater bodies.
7. What are the main uses of water as a raw material?

16.1.2. *New terms and expressions*

agricultural	rolniczy
aluminium (US aluminum)	aluminium, glin
aquifer	warstwa wodonośna
billion	miliard
circulate	krążyć
condensation	skraplanie
content	zawartość
cooling water	woda chłodząca
cubic metre	metr sześcienny
drinking water	woda pitna
droplet	kropla
the Earth’s surface	powierzchnia ziemi
electrical power generation	produkcja energii elektrycznej
enormous	ogromny
essential component	zasadniczy element
evaporation	odparowanie
experience	doświadczać
freshwater	woda słodka
glacier	lodowiec
global amount / global numbers	światowe zasoby
groundwater	wody podziemne
humidity	wilgotność

hydrologic cycle	obieg hydrologiczny
hydrosphere	hydrosfera
ice	lód
indispensable	niezastąpiony
irrigation	nawadnianie
lake	jezioro
partial pressure	ciśnienie (prężność) cząstkowe
percentage	udział procentowy
pond	staw
raw	surowy, nieprzetworzony
reservoir	zbiornik retencyjny
resource	źródło
river	rzeka
rock formation	utwór skalny
saline water	woda słona
saturated vapour pressure	ciśnienie (prężność) pary nasyconej
scarcity	niedobór
snow	śnieg
snowpack	zmarzlina
solar-power	energia słoneczna
store	magazynować
stream	strumień
supply	zasilanie
suspend	zawiesić
sustain	podtrzymać, zrównoważyć
terrestrial	lądowy
transpiration	transpiracja
trap	uwięzić
vapour (US vapor)	para

16.1.3. *Exercises*

1. Match the corresponding phrases

circulation of water
condensation
content of water vapour in air
freshwater bodies
global percentage of saline (salt) waters
lakes and rivers
major uses of water
the origin of energy consumed by the evaporation of water
the percentage of freshwater which is in liquid form
the percentage of people experiencing water scarcity
snow, ice, glacier
water stored under the Earth's surface

10%
13%
98%
cooling and irrigation
conversion of vapour to liquid
groundwater
humidity
hydrologic cycle
lakes, ponds, reservoirs
main sources of drinking water
solar
solid forms of water

2. Which statements are true (T) and which are false (F)?

a. Freshwater constitutes 50% of global water resources. T / F
b. The major global uses of water are for cooling and irrigation. T / F
c. In 2025 about 38% of the human population will be experiencing a scarcity of water. T / F
d. Some species of bacteria can survive without water at all. T / F
e. Water enters the atmosphere by the evaporation of liquid water. T / F
f. Most freshwater is trapped as snow, snowpack, ice and glaciers. T / F
g. The water located under the Earth's surface is found in reservoirs. T / F

16.2. The pollution, purification and disinfection of water

The pollution of natural waters is a worldwide problem. Water pollutants may be both chemical and biological in character. The most important classes of chemical pollutants include heavy metals (such as cadmium, lead or arsenic), organometallic compounds (e.g. alkylmercury or organotin derivatives), inorganic pollutants (e.g. cyanides, hydrogen sulphide, ammonia, nitrites and nitrates, as well as an excess of natural phosphates or fluorides), organic pollutants (e.g. oxygen- consuming faecal matter and food waste, detergents, pesticides, polychlorinated biphenyls) and radionuclides (radium, strontium or caesium). Biological pollution is caused by algae as well as pathogens such as bacteria, viruses and some protozoa.

Water pollution is generally characterized by oxygen parameters, such as dissolved oxygen, biochemical oxygen demand and chemical oxygen demand, but also by the acidity, alkalinity, salinity, taste, odour and colour of the water. A detailed specification of water quality demands the determination of over 50 parameters, including individual concentrations of particular elements and compounds as well as physicochemical parameters.

Water from natural sources usually requires varying degrees of treatment before it is suitable for use in households or industrial applications. The first step in the purification process is aeration. Bubbling air through water effectively removes dissolved gases such as hydrogen sulphide and other volatile organic compounds, which in turn significantly reduce any unpleasant odour. Another advantage of aeration is that soluble iron (II) is oxidized to insoluble iron (III), which can be readily removed from water as a suspension. If water is excessively hard, calcium and magnesium ions are removed by the addition of lime in the next step.

Water is disinfected by adding elemental chlorine or ozone. The use of chlorine, though, leads to the formation of undesirable organic pollutants called trihalomethanes. But this problem can be avoided by the alternative use of chlorine dioxide. Recently, new advanced oxidation technologies have been introduced at the final stage of water treatment. They involve ultraviolet irradiation combined with the use of catalysts or oxidizing agents, followed by micro- or ultrafiltration.

16.2.1. *Reading comprehension*

1. What is the nature of water pollutants?
2. What are the most important classes of chemical pollutants?
3. Name the main biological pollutants commonly found in natural waters.
4. Explain the meaning of ‘oxygen parameters’.
5. What technological process is primarily used for the purification of water?
6. Why are excess magnesium and calcium removed during purification?
7. What are the main agents used for disinfecting water?
8. Explain the term ‘advanced oxidation technology’.

16.2.2. *New terms and expressions*

acidity	kwasowość
advanced oxidation technologies	techniki pogłębionego utleniania
aeration	napowietrzanie
alga, algae	glon, glony
alkalinity	zasadowość
alkylmercury	alkilortęć
allow	pozwolić
ammonia	amoniak
arsenic	arsen
biochemical oxygen demand	biochemiczne zapotrzebowanie na tlen BZT
bubble	bąbelek, przepuszczać gaz przez ciecz

cadmium	kadm
catalyst	katalizator
cause	powodować, przyczyniać się do
caesium (US cesium)	cez
chemical oxygen demand	chemiczne zapotrzebowanie na tlen ChZT
chlorine	chlor
chlorine dioxide	dwutlenek chloru
colourless	bezbarwny
container	zbiornik, naczynie
cyanide	cyjanek
derivative	pochodna
detergent	środek piorący, detergent
disinfection	dezynfekcja
dissolve	rozpuszczać
dissolved oxygen	tlen rozpuszczony
evaluation	ocena, badanie
excessive	nadmierny
faecal matter, faeces (US fecal matter, feces)	odchody
fluoride	fluorek
food waste	odpadki żywności
hard water	twarda woda
heavy metals	metale ciężkie
household	gospodarstwo domowe
hydrogen sulphide	siarkowodór
individual	poszczególny, indywidualny
industrial	przemysłowe
insoluble	nierozpuszczalny
introduce	wprowadzić
involve	polegać na, sprowadzać się do
lead	ołów
lime	wapno (tlenek wapnia)
nitrite	azotan(III), azotyn
nitrate	azotan(V), azotan

occur	zachodzić, zdarzać się, występować
odour (US odor)	zapach
organometallic compounds	związki metaloorganiczne
organotin	związki organocyny
ozone	ozon
pesticide	pestycyd
phosphate	fosforan
physicochemical	fizyko-chemiczne
plumbing	orurowanie, praca hydraulika
pollutant	substancja zanieczyszczająca
pollution	zanieczyszczenie
polychlorinated biphenyls	polichlorowane bifenyle
precipitate	wytrącić (osad), osad
protozoa	pierwotniaki
purify	oczyszczać
radionuclides	radionuklidy
radium	rad
readily	swobodnie, z łatwością
reddish	czerwonawy
salinity	zasolenie
sample	próbka
soluble	rozpuszczalny
strontium	stront
suspension	zawiesina
taste	smak
transparent	przeźroczysty
trihalomethanes	trihalometany
turbid	mętny, nieprzeźroczysty
ultraviolet irradiation	naświetlanie promieniowaniem UV
volatile organic compounds	lotne związki organiczne
water treatment	oczyszczanie wody
worldwide	o światowym zasięgu

16.2.3. *Exercises*

1. Fill in the blanks

Pollution of water may be of chemical as well as of ………………… character. Common examples of heavy metals are ……..........., ……………. and ……………. Detergents, pesticides or polychlorinated biphenyls are examples of ……….. ………….. . The general characterization of pollution may be expressed by oxygen parameters such as ……………. oxygen or ………………. oxygen ………………. . ……………… is usually the first step in water purification. It reduces ……………… due to the removal of gases such as ………… sulphide. During this process, …………… iron (II) is oxidized to …………… iron (III). Calcium and magnesium must be removed from waters that are …………………….. hard. The addition of chlorine or ozone to treated water is an important stage of the process called …………… . Advanced oxidation technologies combine ultraviolet irradiation with the use of …………………….. .

2. Write two – three sentences on the following problems.

1. What do you think is the origin of the word ‘plumbing’?
2. Explain how outdated water supply systems could be a source of toxic metals?
3. What is the purpose of water aeration?
4. When a sample of groundwater is taken from a source, it is initially transparent and colourless. However, if it is allowed to stand in an open container, it quickly turns reddish and turbid. Finally, a reddish-brown solid precipitates. What can you say about the composition of this water? Try to explain the processes occurring in such a sample of water.

16.3. Groundwater and its pollution

Most of the freshwater on our planet is located underground, half of it at depths of over one kilometre. Underground water ranges in age from a few to millions of years. The ultimate source of groundwater is meteoric water from rain or snow that percolates down to (infiltrates) aquifers. An aquifer (a kind of underground reservoir) is formed when groundwater drenches layers of porous or highly fractionated rocks. These are usually sands, sandstones or gravels. At the bottom, the aquifer is bounded by an impermeable layer such as clay. Constant infiltration into the aquifer occurs in so-called recharge zones. The layer where all the pores are filled with water is referred to as the saturated zone. The top of this zone is called the water table.

Groundwater is usually extracted through wells – they are the source of drinking water for nearly half the world’s human population.

Historically, groundwater used to be considered the purest form of natural water. Indeed, due to the infiltration process and the long residence time underground, groundwater contains much less organic matter than surface water. Also, most of the microorganisms are usually filtered out as the groundwater collects in the aquifer. Groundwater, however, may dissolve minerals from the rock formations through which it passes. Occasionally, the content of undesirable compounds (including dissolved salts) may become excessively high.

The nitrate ion is the inorganic contaminant of groundwater that is of the greatest concern. It originates from the application of nitrogenous fertilizers, sewage collected in septic tanks and atmospheric deposition. Typical organic contaminants found in most groundwater supplies are chlorinated solvents (especially tri- and tetrachloroethene), BTX hydrocarbons and other petroleum products, including MTBE.

The decontamination of groundwater usually involves pump-and-treat systems that pump raw water from the aquifer, treat it to remove the contaminants and return the purified water to the aquifer or to some other water body.

16.3.1. *Reading comprehension*

1. What is the age range of groundwater?
2. Where does groundwater originate?
3. Explain the term ‘aquifer’.
5. How is groundwater usually extracted?
6. Why does groundwater contain less organic matter and fewer microorganisms than surface waters?
7. What are the main sources of nitrate compounds in groundwater?
8. Name some typical organic contaminants found in groundwater.

16.3.2. *New terms and expressions*

atmospheric deposition	opad atmosferyczny
bottom	dno, dół (dolna część)
BTX compounds (benzene, toluene, ethylbenzene, xylene)	substancje z grupy BTX (benzen, toluen, etylobenzen, ksylen)
bulk	większość
chlorinated solvent	rozpuszczalnik chlorowcoorganiczny
clay	glina (minerał ilasty)
composed of (consists of)	złożony z
contaminant	czynnik odpowiedzialny za skażenie
decontamination	oczyszczenie, odkażenie
dissolved salts	sole rozpuszczone
drench	nasączyć, przemoczyć
excessively	nadmiernie
extract	wydobyć
fertilizer	nawóz
filter out	odfiltrować
fractionate	frakcjonować, dzielić na frakcje
gravel	żwir
human sewage	ścieki bytowe
hydrocarbon	węglowodór
impermeable	nieprzenikalny, nieprzepuszczalny
infiltrate	przenikać
layer	warstwa

meteoric water	woda z opadów
MTBE methyl tert-butyl ether	eter tert-butylometylowy
nitrate	azotan
organic matter	materia organiczna
percolate	przesączać się, przenikać
petroleum products	ropopochodne
pore	por (niewielki otwór)
porous	porowaty
precipitation	opad (atmosferyczny)
pure	czysta
purification	oczyszczanie
raise (be of) concern	budzić obawy
range	zakres
raw	surowy, nieoczyszczony
recharge zone	strefa zasilania
residence time	czas przebywania
rock	skała
sand	piasek
sandstone	piaskowiec
saturated zone	warstwa nasycona
septic tank	szambo
ultimate	ostateczny
underground	pod ziemią, podziemny
undesirable	niechciane, niepożądane
water table	lustro wody
water well	studnia wodna

16.3.3. *Exercises*

1. Match corresponding phrases.

age of groundwater
aquifer
chlorinated solvent
location of groundwater
meteoric waters
nitrate
porous rock
recharge zone
septic tank
system of groundwater decontamination
utility for groundwater extraction

area above the aquifer
from a few to millions of years
major groundwater contaminant
pump-and-treat
sand, gravel
snow and rain
source of nitrogen in groundwater
trichloroethene
underground
underground reservoir
water well

2. Which statements are true (T) and which are false (F).

a. Water wells are used for the decontamination of groundwater. T / F
b. The ultimate source of groundwater is rain or snow. T / F
c. The bulk of global freshwater is located in rivers and lakes. T / F
d. An aquifer may be defined as an underground reservoir. T / F
e. Groundwater contains a high content of organic matter. T / F
f. The age of underground water is counted in billions of years. T / F
g. Nitrogen fertilizers may be an effective source of nitrate ions in groundwater. T / F

16.4. Wastewater treatment

Wastewater treatment technology usually involves three general stages: (i) mechanical treatment (the primary stage), (ii) biological treatment (the secondary stage), and finally (iii) chemical (or advanced) treatment (the tertiary stage). The aim of the primary stage is to remove large particles and coarse suspended matter from the wastewater by means of sedimentation and filtration. The sewage sludge formed at this stage is removed before the next stages in the treatment.

This pre-purified water is then sent to the second stage of treatment – biological oxidation by microorganisms. Usually, this stage is conducted in an aerated bioreactor filled with activated sludge. Activated sludge is an aqueous suspension of living microorganisms that metabolize degradable matter. This metabolic activity leads to the conversion of most organic compounds to carbon dioxide, ammonia, nitrates, phosphates and other simple inorganic chemicals. This process is called mineralization. The biological oxidation in this second treatment stage reduces the Biochemical Oxygen Demand (BOD) parameter. Nitrification, occurring at this stage, converts organic nitrogen to nitrates.

In many cases, these two steps are sufficient and the treated water is discharged into the environment after dilution with natural water. Treated water may also be used as a water source for municipalities if an additional disinfection step is included before use.

Some types of wastewater require the tertiary stage of treatment. This process aims to remove specific substances depending on local circumstances, the nature of the wastewater and the final destination of the purified waters. This step may include: (i) further reduction of BOD, (ii) removal of dissolved organic chemicals by adsorption on activated carbon, (iii) removal of phosphates by reaction with calcium hydroxide, (iv) removal of heavy metals by the addition of hydroxides or sulphides and (v) removal of iron by aeration at a high pH. In very special cases the treatment may also involve the removal of excess inorganic ions. For example, ammonium ions are eliminated at high pH by adding lime, followed by bubbling air through the water.

16.4.1. *Reading comprehension*

1. What are the three general steps in wastewater treatment technology ?
2. What fraction of sewage is removed during the primary stage of treatment ?
3. What are the principles of activated sludge technology ?
4. What is activated sludge composed of ?
5. What are the final products of mineralization?
6. What water quality parameters are improved during biological treatment ?
7. Give examples of tertiary treatment technologies.

16.4.2. *New terms and expressions*

activated carbon	węgiel aktywny
activated sludge	osad czynny
adsorption	adsorpcja
advanced treatment	oczyszczenie pogłębione
aerate, aeration	napowietrzać, napowietrzanie
ammonia, ammonium ion	amoniak, jon amonowy
biological treatment	oczyszczanie biologiczne
bioreactor	bioreaktor
bubbling	przepuszczanie gazu przez ciecz, bulgotanie
calcium hydroxide	wodorotlenek wapnia
carbon dioxide	dwutlenek węgla
circumstance	okoliczność, uwarunkowanie
coarse	gruboziarnisty
conduct	prowadzić
conversion	konwersja, przemiana
degradable	degradowalny, usuwalny
destination	miejsce przeznaczenia
discharge	zrzucać, opróżniać
disinfection	dezynfekcja
dissolve	rozpuszczać
filtration	filtrowanie
heavy metals	metale ciężkie
mechanical treatment	oczyszczanie mechaniczne

metabolic, metabolize	metaboliczny, metabolizować
microorganism	mikroorganizm
mineralization	mineralizacja
municipality	miasto, gmina miejska
nitrate	azotan
nitrification	nitryfikacja
organic nitrogen	organiczne związki azotu
oxidation	utlenianie
particle	cząstka
phosphate	fosforan
pre-purified	wstępnie oczyszczony
primary	pierwszego stopnia, pierwszorzędowy
remove	usunąć
secondary	drugiego stopnia, drugorzędowy
sedimentation	osadzanie, sedymentacja
sewage sludge	osad ściekowy
subsequently	w następnej kolejności
sulphide	siarczek
suspend, suspension	zawiesić, zawiesina
tank	zbiornik
technology	technologia, technika
tertiary	trzeciego stopnia, trzeciorzędowy
wastewater	ścieki
wastewater treatment	oczyszczanie ścieków
wastewater treatment plant	oczyszczalnia ścieków

16.4.3. *Exercises*

1. Fill in the blanks

The processing of wastewater starts with …………… treatment, followed by ………….. oxidation. During the primary stage larger ……………...... and .... are removed. Secondary treatment is usually based on ……………. sludge technology. This process exploits the metabolic activity of living microorganisms, leading to a significant reduction in ………….. oxygen …………….. . Biological oxidation also leads to the …………….. of the nitrogen organic compounds. The third step of treatment is also called the …………… stage, in which specific chemicals are removed. Activated ....…..……… is used for removing dissolved ………….....… compounds, while adding calcium hydroxide helps to remove …………….............. .

2. Classify the following processes as the primary, secondary or tertiary stage of wastewater treatment.

Process	**Stage of treatment**
removal of heavy metals	
reduction of BOD	
adsorption on activated carbon	
nitrification	
filtration	
biological oxidation	
conversion to carbon dioxide	
aeration at high pH	
suspension removal	
addition of sulphates	
removal of large particles	

17. Toxic Chemicals and their Effects

17.1. Pesticides

Pesticides are substances that control the growth of unwanted organisms, such as insects, fungi or plants. The names for these particular examples would be: insecticides, fungicides and herbicides. There are many other types of pesticides, including bactericides to control bacteria and algicides used against algae.

The industrial production of pesticides started in the 1940s, focusing mainly on organochlorine compounds. Many organochlorines have several properties in common, such as high stability, low solubility in water, high solubility in fats and other hydrocarbon-like environments, and a relatively high toxicity towards insects. Most of these pesticides are no longer in use, however, since their adverse effects on many environmental compartments as well as on human health have been amply demonstrated. Typical examples of organochlorines are DDT (p-dichlorodiphenyltrichloroethane), hexachlorobenzene, mirex, dieldrin, aldrin or endosulphan. All of them are nowadays classified as persistent organic pollutants (POPs) and some of them are members of the ‘dirty dozen’, the group of 12 POPs listed by the United Nations Environmental Programme as being banned by international agreements. These compounds are not only hazardous in their native form – their various metabolites are as well. A very well-known biologically active metabolite of organochlorine is DDE (dichlorodiphenyldichloroethane), a metabolite of DDT. It was found that in some birds DDE interferes with the enzyme responsible for the distribution of calcium, so contaminated birds produced eggs with shells too thin to withstand the weight of the brooding parents.

Many organochlorine compounds can be bioaccumulated, especially by aquatic organisms. For example, when contaminated water passes through a fish’s gills, these compounds selectively diffuse from the water into fish’s fatty flesh and become more concentrated there. The level to which a chemical is bioconcentrated in a particular organism is given by the bioconcentration factor BCF. Its value can be predicted from a simple comparison with the octanol – water partition coefficient of the chemical. In general, the higher the octanol – water partition coefficient, the more likely the chemical is to be bound to the fatty tissue of the living organism.

Organophosphorus insecticides are a non-chlorine alternative to the organochlorines. These compounds are generally non-persistent and non-bioaccumulative since they decompose in the environment within a few days or weeks. However, they have been shown to be much more acutely toxic to humans than organochlorines were. Typical examples of these insecticides are dichlorvos, parathion, diazinon or malathion. Their insecticidal potency results from the inhibition of acetylcholinesterase – an enzyme in the nervous system responsible for destroying the acetylcholine molecule, which transfers a signal from one cell to another.

17.1.1. *Reading comprehension*

1. What are the main types of pesticides?
2. Why are organochlorine pesticides not in use anymore?
3. What are POPs?
4. Why do organochlorine pesticides bioaccumulate in living systems?
7. What chlorine-free alternatives of pesticides are there?
8. What is the toxicological mode of action of organophosphorus pesticides?

17.1.2. *New terms and expressions*

‘dirty dozen’	parszywa dwunastka
acetylcholine	acetylocholina
acetylcholinesterase	acetylocholinoesteraza
acutely toxic	ostro toksyczny
adverse	niekorzystny
aldrin	aldryna
algicide	algicyd
bactericide	bacteriocyd
banned	zabroniony
bioaccumulation	bioakumulacja
bioconcentration factor	współczynnik biokoncentracji
contaminated	skażony
dangerous	niebezpieczny
diazinon	diazinon
dichlorodiphenyldichloroethane	dichlororodifenylodichloroetan

dichlorvos	dichlorofos
dieldrin	dieldryna
endosulphan	endosulphan
environmental compartment	element środowiska
fungi	grzyby
fungicide	fungicyd
hazardous	niebezpiecznie szkodliwy
herbicide	herbicyd
hexachlorobenzene	heksachlorobenzen
hydrocarbon-like	węglowodoropodobne
insect	owad
insecticide	insektycyd
international agreement	umowa międzynarodowa
malathion	malation
metabolite	metabolit
mirex	mireks
native form	forma pierwotna
nervous system	układ nerwowy
non-bioaccumulative	nie bioakumulujący się
organochlorinated	chlorowcoorganiczny
organochlorines	związki chlorowcoorganiczne
organophosphorus compounds	związki fosfoorganiczne
parathion	paration
partition coefficient	współczynnik podziału
p-dichlorodiphenyltrichloroethane	p-dichlorodifenylotrichloroetan
persistent organic pollutants (POPs)	trwałe zanieczyszczenia organiczne
plant	roślina
shell	skorupa
toxicity	toksyczność
United Nations Environmental Programme	Program Ochrony Środowiska ONZ
withstand	wytrzymać

17.1.3. *Exercises*

1. Match the corresponding phrases

12 chemicals banned by international agreements	adverse effects to health and the environment
DDT	bioaccumulation
dichlorodiphenyldichloroethane	dirty dozen
inhibition of acetylcholinesterase	the nineteenforties
organophosphate insecticides	high stability, low solubility in water
persistent organic pollutants	insecticidal potency of organophosphates
pesticides	DDT metabolite
potential for buildup in fatty tissues	non-chlorine alternative pesticides
properties of organochlorines	p-dichlorodiphenyltrichloroethane
reasons for banning organochlorines	POPs
the starting date of industrial production of pesticides	substances that control growth of pests

2. Indicate which statements are true (T) and which are false (F).

a. Pesticides are substances that control the growth of insects only. T / F

b. Organochlorine compounds were the first pesticides to be produced on an industrial scale. T / F

c. DDT is a typical example of an organochlorine compound. T / F

d. The ‘dirty dozen’ is a list of all the pesticides produced before 1956. T / F

e. Thinning of bird eggshells is caused by DDE, a metabolite of DDT. T / F

f. Organophosphorus compounds consist of phosphorus, carbon and chlorine atoms. T / F

g. Organophosphorus compounds owe their insecticidal properties to the inhibition of acetylcholinesterase. T / F

h. Organochlorines are more acutely toxic to humans than organophosphorus compounds. T / F

17.2. Non-pesticide organic contaminants

The widespread production and use of organic chemicals has led to their presence in the environment, which in many cases is permanent and persistent. Non-pesticide organic contaminants include several types of chemicals of the highest environmental concern: polychlorinated dibenzodioxins and dibenzofurans (the so-called dioxins), polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs).

Dioxins are formed during the production of tetrachlorophenol in one of the side reactions. Moreover, polychlorinated dibenzodioxins and dibenzofurans are by-products of the following processes: pulp bleaching in the paper industry, the incineration of municipal and industrial waste, the recycling of metals or the production of chlorinated solvents. In total there are 75 different dibenzodioxins containing one to eight chlorine atoms substituted at various positions of both aromatic rings. They are congeners, that is, members of a chemical family that differ only in the number and position of the same substituents.

PCBs are a group of industrial chemicals characterized by many attractive properties such as non-flammability, low vapour pressure, inertness, low cost and excellent electrical insulation properties. Therefore, for years they were extensively used as coolant fluids in power transformers, as plasticizers in PVC production, as de-inking solvents in recycling, as heat transfer fluids for machinery and in many more applications. Like many other organochlorine compounds, they are persistent in the environment and bioaccumulate in living systems. Both PCBs and dioxins are listed in the ‘dirty dozen’ list, not only because they are toxic in their own right, but also because they can also have their mutagenic and sometimes even carcinogenic properties.

PAHs are common air pollutants that enter the environment from a number of sources, including the exhaust of petrol engines, volcanic eruptions, and the combustion of fossil fuels where conversion to CO or CO_2 is incomplete. PAHs are also present in cigarette smoke and in charred or burnt food. They consist of several aromatic, benzene-like rings fused together by the sharing of a pair of adjacent carbon atoms. Although PAHs make up only about 0.1% of airborne particulate matter, their existence as air pollutants is of concern since many of them are carcinogenic. Benzo(a)pyrene is the most notorious and common carcinogenic PAH.

17.2.1. *Reading comprehension*

1. What are the main types of non-pesticide persistent organic pollutants?
2. What are the main sources of dioxins in the environment?
3. What are congeners?
4. What properties of PCBs made them attractive to industry?
5. What were the main industrial applications of PCBs?
6. What are the main sources of PAHs in the environment?
7. What feature of PAHs makes them hazardous to man and the environment?

17.2.2. *New terms and expressions*

adjacent	sąsiadujący
air pollutants	zanieczyszczenia powietrza
airborne particulate matter	pył zawieszony
benzo(a)pyrene	benzo(a)piren
bleaching	wybielanie
burnt (also ‘burned’)	spalony
by-products	produkty uboczne
carcinogenic	kancerogenny
charred	zwęglony
chlorinated solvents	rozpuszczalniki chloro-organiczne
combustion	spalanie
concern (in the expression ‘to be of concern’)	problem, sprawa, zmartwienie
congeners	kongenery
coolant fluid	płyn chłodzący
de-inking solvent	rozpuszczalnik odbarwiający
engine	silnik
exhaust	wydech
extensively	dokładnie, wyczerpująco, szeroko
fossil fuels	paliwa kopalne
heat transfer	przenoszenie ciepła

incineration	spalanie
incomplete	niepełny
insulation	izolacja, izolacyjny
municipal	komunalny
mutagenic	mutagenny
non-flammability	niepalność
non-pesticide organic contaminants	zanieczyszczenia organiczne nie będące pestycydami
non-reactivity	niereaktywność
notorious	uciążliwy
permanent	trwający, permanentny
persistent	trwały, uciążliwy
petrol (US gasoline)	benzyna
plasticizer	plastyfikator
polyaromatic hydrocarbons (PAHs)	wielopierścieniowe węglowodory aromatyczne
polychlorinated biphenyls (PCBs)	polichlorowane bifenyle
polychlorinated dibenzodioxins	polichlorowane dibenzodioksyny
polychlorinated dibenzofurans	polichlorowane dibenzofurany
(power) transformer	transformator
pulp	pulpa papiernicza, breja
substituent	podstawnik
tetrachlorophenol	tetrachlorofenol
volcanic eruption	wybuch wulkanu
widespread	rozpowszechniony

17.2.3. *Exercises*

1. Fill in the blanks

Among the non-pesticide organic contaminants, those of the greatest environmental concern are …………, ………….. and ………… . Dioxins are formed mainly during the manufacture of ……………., but they are also produced during the ………………. of municipal and industrial waste. The 75 isomers of dioxins differing in the number and position of the chlorine substituents in the structure are ………… . PCBs were used for years as ……….. fluids in ………… transformers and as ……………. in PVC production. ….. are common air pollutants emitted to the atmosphere from the exhausts of petrol engines, volcanic eruptions and the incomplete combustion of ……….... fuels. ………………… is the most notorious and common carcinogenic PAH.

2. Questions and problems.

a. Give the common physicochemical properties of non-pesticide organic contaminants.
b. Explain how bleaching can lead to the formation of dioxins.
c. Give three examples of non-pesticide organic contaminants other than dioxins, PCBs and PAHs.
d. How one can limit the emission of non-pesticide organic contaminants to the environment?

17.3. Heavy metals

Heavy metals are metallic elements with relatively high atomic numbers. Their densities are high compared to those of other common materials. Some heavy metals are considered extremely troublesome and toxic pollutants, particularly mercury, lead, cadmium, chromium and arsenic.

Cadmium is widely used in metal plating as well as in making small batteries. Cadmium is very toxic, destroying red blood cells and damaging kidney tissue. Lead is the most common heavy metal pollutant because of its widespread use in industry. Metallic lead is used in the manufacture of car batteries and in plumbing, and lead compounds used to be used as anticorrosive pigments in paints and as petrol additives. Exposure to lead adversely affects the neurological and reproductive system.

Mercury is employed in hundreds of applications, many of which utilize its unusual property of being a liquid metal at room temperature. Mercury or its compounds are used in electrical switches, fluorescent and mercury lamps, batteries and thermometers. When entering the environment mercury may undergo alkylation to give methylmercury and dimethylmercury, both very toxic organometallic compounds. The so-called Minamata Bay incident has been the worst case of poisoning from methylated forms of mercury in recent times. The water in Minamata Bay, Japan, was polluted by the drainage of mercury-containing wastes from a chemical plant, which in turn led to poisoning in the local people as a result of their consuming fish and seafood from the bay.

Arsenic is a metalloid (on the borderline between metals and non-metals in the periodic table), but its environmental and toxicological effects are much like those of heavy metals. Arsenic(III) oxide has been the poison of choice for murder and suicide since ancient times. Before the introduction of modern pesticides, large quantities of arsenic compounds were used to control pests on crops. Today, arsenic is one of the most serious environmental health hazards, being found in natural waters and drinking water at relatively high concentrations. Arsenic is carcinogenic to humans, and also causes cardiovascular diseases and disrupts hormonal processes.

Chromium is widely used for electroplating, corrosion protection and leather tanning. As a consequence of industrial emissions chromium is a common water pollutant. The toxicity of chromium depends on its oxidation state. Hexavalent chromium is highly toxic and chromate(VI) ions – a suspected carcinogen – readily enter cells, where they can oxidize nucleic acid bases. Trivalent chromium is considered much less harmful, even functioning as a trace nutrient.

17.3.1. *Reading comprehension*

1. What are heavy metals?
2. Which heavy metals are particularly dangerous to the environment?
3. What are the main fields of application of cadmium and lead?
4. What are the main products of the alkylation of mercury?
5. What happened in Minamata Bay?
6. Why is arsenic considered to be one of the most serious environmental health hazards?
7. Does the oxidation state of chromium affect its toxicity?

17.3.2. *New terms and expressions*

abnormal	nienormalny
additive	dodatek
alkylation	alkilowanie
ancient	antyczny
anticorrosive	przeciwkorozyjny
aqueduct	akwedukt
arsenic	arsen
arsenic(III) oxide	tlenek arsenu(III)
bay	zatoka
cadmium	kadm
cardiovascular disease	choroba sercowo-naczyniowa
channel	kanał
chemical plant	zakłady chemiczne
chromate(VI)	chromian(VI)
chromium	chrom
corrosion protection	zabezpieczenia przeciwkorozyjne
crop	uprawa, plon
dimethylmercury	dimetylortęć
disrupt hormonal processes	zakłócić procesy hormonalne
drainage	zlewanie, ściekanie, zrzucanie
electroplating	elektrogalwanizacja
exposure	narażenie
felt	filc
hatter	rzemieślnik wyrabiający kapelusze (kapelusznik)
heavy metals	metale ciężkie
hexavalent	sześciowartościowy
kidney	nerka
knead	ugniatać, miętosić
lead	ołów
leather tanning	garbowanie skóry
line	wyłożyć, wysłać, pokryć
manufacture	produkować

mercury	rtęć
metalloid	półmetal
methylmercury	metylortęć
monastery	klasztor
monk	mnich
murder	morderstwo
neurological	neurologiczny
nickname	przezwać, przezwisko
nucleic acid bases	zasady nukleinowe
organometallic compounds	związki metaloorganiczne
oxidation state	stopień utlenienia
pests	szkodnik
plating	galwanizacja
plumbing	przyłącza hydrauliczne
poison	trucizna
red blood cells	czerwone ciałka krwi
reproductive	rozrodczy
seafood	żywność pochodzenia morskiego
suicide	samobójstwo
switch	przełącznik
tanning	garbowanie
trivalent	trójwartościowy
troublesome	problematyczny
tub	balia, wanna
wastes	odpady
wine	wino

17.3.3. *Exercises*

1. Complete the table showing the adverse effects and typical applications of heavy metals.

Heavy metal	**Adverse effect**	**Typical application**
Cadmium	very toxic, destroys red blood cells, ...	metal plating, ...
Lead		
Mercury		
Arsenic		
Chromium		

2. Problems and questions.

a. Mercury(II) nitrate used to be utilized as a tanning agent in the manufacture of hats in the 19th century. To obtain felt, a fashionable material for men's and women's hats, workers kneaded rabbit skins in mercury nitrate solution contained in large, open tubs. What do you think is the origin of the saying ‘to be as mad as a hatter’, which comes from those times?

b. The ancient Romans drank water carried to Rome from distant places along aqueducts. These water-carrying channels were lined with lead. Could this have had an effect on people's health?

c. Lead(II) acetate is sweet to taste; it even used to be known as ‘lead sugar’. The bones of monks who lived in a certain German monastery in the fifteenth century show an abnormally high content of lead. At that time the monastery was famous for its delicious, sweet wine. Given this information, can you give a possible cause of death of the monks?

17.4. Principles of toxicology

Ultimately, most pollutants and hazardous substances are of concern because of their toxicity. The study of the harmful effects of these substances on living organisms is called toxicology. The substances of interest (toxicants) include both synthetic compounds and those that exist naturally in the environment.

In toxicology, the adverse effects are determined by injecting test organisms with the toxicant and observing how their health is affected. Test organisms may be animals but also specific eukaryotic cell lines or bacterial cells. With these tests, acute toxicity can be determined, which is the rapid onset of symptoms including the death of the test organism following the intake of a dose of the toxicant. In order to understand the long-term effects of toxicants, a much better reflection of environmental conditions, it is preferable to measure chronic (long-term, continuous) toxicity. This is determined at relatively low individual doses of a toxic substance that is present in the environment of the exposed organism (food, water, air).

Furthermore, chemical interactions between toxicants may affect their biological properties. When two different substances have the same physiological impact, their effects may be additive or synergistic. Synergy means that the total effect is greater than the sum of the separate effects. Additionally, potentiation may occur when an inactive substance enhances the action of an active one. Conversely, there is also antagonism, when an active toxicant decreases the toxicity of another active one.

The most common way of illustrating the effect of varying concentrations on the test organism is the dose-response curve. The dose of the chemical is plotted on the x axis and the measured effect (death, growth inhibition) is shown on the y axis. The dose that proves to be lethal to 50% of the population is called the lethal dose (LD_{50}) value of the substance. The range of LD_{50} values for the acute toxicity of various chemicals is enormous. Highly toxic substances such as tetanus or botulism toxins have an LD_{50} at the level of 10^{-8} g per kg of body weight. The LD_{50} values of organophosphorus pesticides such as parathion are at the level of 10^{-3} g kg^{-1} and those of DDT are around 10^{-1} g kg^{-1}. Substances with LD_{50} values of many grams per kg of body weight (e.g. sugar) are classified as practically non-toxic, though according to Paracelsus, all substances are toxic in sufficiently high doses. For some toxicants there is a certain dose below which none of the test organisms are affected. This dose is called the ‘no observable effects level (NOEL)’. For chronic exposure, the NOEL dose is normally expressed in milligrams of toxicant per kilogram of body weight per day.

17.4.1. *Reading comprehension*

1. What is the most general definition of toxicology?
2. How are the adverse effects of toxicants usually determined? What test systems are used?
3. What is the difference between acute and chronic toxicity?
4. How may the effects of varying the dose to the organism be illustrated?
5. What do LD_{50} and NOEL stand for?
6. Name the strongest and weakest toxicants mentioned in the text.

17.4.2. *New terms and expressions*

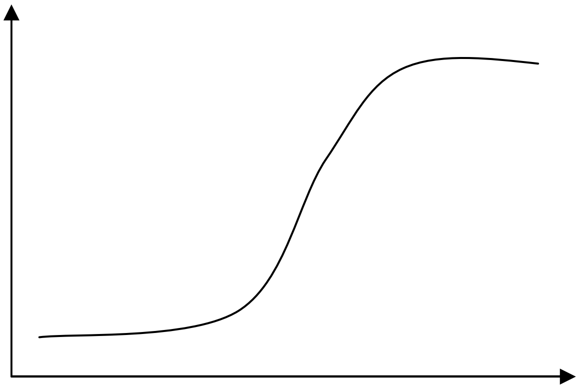
acute toxicity	toksyczność ostra
additive	sumujący się
affect	wpływa
antagonism	antagonizm
bacterial	bakteryjny
botulism	jad kiełbasiany
chronic toxicity	toksyczność chroniczna
dose	dawka
dose – response curve	krzywa dawka – efekt
enhance	wzmagać
enormous	ogromny
eukaryotic cell lines	linie komórek eukariotycznych
growth inhibition	zahamowanie wzrostu
harmful	szkodliwy
hazardous substance	substancja niebezpieczna
injecting	wprowadzanie (przez zastrzyk)
lethal	śmiertelny

no observable effects level (NOEL)	najniższy poziom (dawki, stężenia) przy którym nie obserwuje się szkodliwych zmian
onset	rozpoczęcie
pollutant	zanieczyszczenie
potentiation	potencjacja, wzmaganie
synergistic	synergiczny
synthetic	syntetyczny
tetanus	tężec
toxicants	substancja toksyczna, toksykant
toxicology	toksykologia
ultimately	w ostateczności
x axis, y axis	oś x, oś y

17.4.3. *Exercises*

1. The figure shows a typical dose – response curve. Complete the graph with appropriate labels.

- Dose (g kg^{-1})
- Death (%)
- LD$_{50}$
- NOEL



2. Match the corresponding phrases.

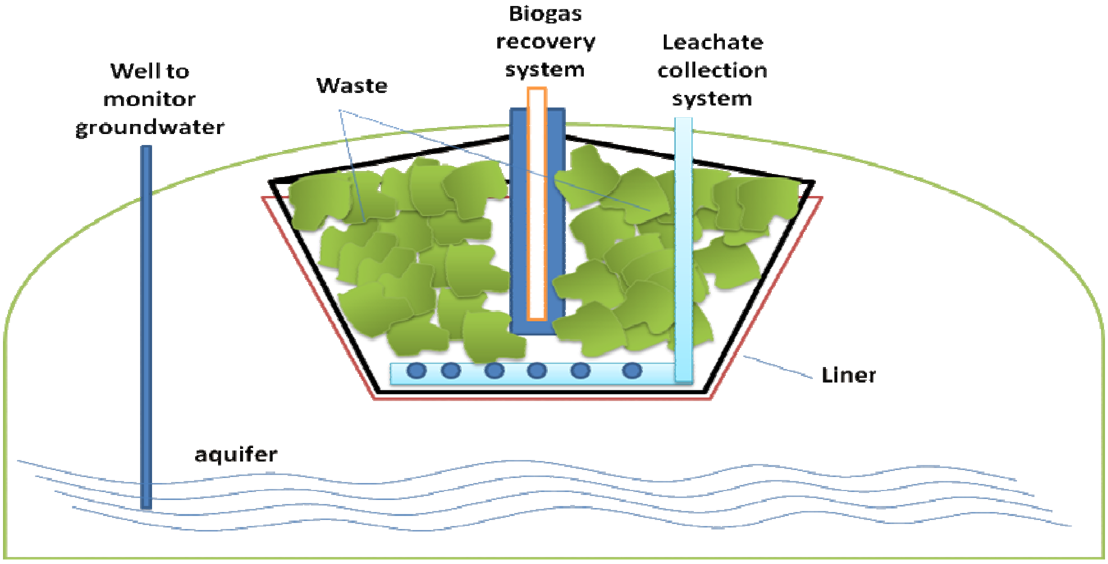
botulin	An active toxicant decreases the toxicity of another one
chronic toxicity	acute toxicity
concentration of toxicant causing death	animals or cell lines
dose	antagonism
dose-response curve	concentration of toxicant
highly toxic substance	effects after longer exposure
immediate adverse effect	graphic expression of toxic effects
lethal dose	LD_{50}
dose lethal to 50% of the population	no observable effects level
NOEL	synergy
the study of the harmful effects of toxicants	total effect greater than the sum of the separate ones
toxicant	toxic substance
toxicity test organisms	toxicology

18. Waste Management

18.1. Disposal of waste in landfills

Nowadays, one of the most common ways of handling municipal solid waste (MSW) is its disposal in a landfill. In the past, landfills were frequently large holes in the ground, usually left after the extraction of clay, sand or gravel. Modern municipal landfills are designed in a much more sophisticated way. They often accept no hazardous waste and are located in places where their impact on the environment is minimal. Municipal solid waste is compacted in layers in order to reduce its overall volume. The daily layer of disposed waste is covered with a layer of soil to prevent its remobilization. After being filled, the landfill is eventually capped with a layer of clay or a plastic membrane.

There are two critical elements of a secure landfill construction: a bottom liner and a leachate collection system. The bottom liner is impermeable to fluids. It is made of one or more layers of clay or a synthetic flexible membrane. The leachate collection system captures contaminated water and other fluids at the bottom of the landfill. Biogas is produced as a result of the anaerobic biodegradation of dumped organic material. It is usually collected and flared off or used to generate electricity in a gas fired power plant. The scheme below presents a typical landfill design:



18.1.1. *Reading comprehension*

1. What is the usual way of disposing of MSW nowadays?
2. What are the main steps of daily waste disposal at a landfill?
3. What happens after the landfill has been filled?
4. How are leachates from the landfill prevented from entering the soil?
5. What type of materials are typically used for the liner?
6. How can the biogas produced in a landfill be utilized?

18.1.2. *New terms and expressions*

anaerobic biodegradation	rozkład beztlenowy
cap	zakryć
clay	glina, ił
compact	ugnieść
disposal	składowanie
flare off	wypalić
flexible	giętki, elastyczny
gas fired power plant	elektrownia zasilana gazem
gravel	żwir
hazardous waste	odpady niebezpieczne
impermeable	nieprzepuszczalny
landfill	składowisko odpadów
leachate	odciek, wysięk
leachate collection system	system drenażowy usuwania odcieków
liner	membrana izolacyjna
municipal solid waste	odpady komunalne (stałe)
nowadays	obecnie, współcześnie
remobilization	wtórne uwolnienie, remobilizacja
sand	piasek
sophisticated	wyrafinowany
synthetic	syntetyczny, sztuczny

18.1.3. *Exercises*

1. Indicate which statements are true (T) and which are false (F).

a. Landfills are the most common way of handling MSW in Poland today. T / F

b. Modern landfills must be isolated from the ground by a layer of clay. T / F

c. Biogas is produced only in landfills where hazardous waste is dumped. T / F

d. The leachate collection system improves groundwater quality in the neighbourhood of a landfill. T / F

e. After being filled, the landfill should be capped with a plastic membrane or a layer of clay. T / F

f. The main components of the biogas produced in a landfill are propane and butane. T / F

g. The daily layer of dumped waste is densely compacted to reduce emissions of odour. T / F

2. Complete the glossary below:

Term	**Explanation**
landfill	*An engineered site where waste is collected with minimal impact on human health and the environment.*
municipal solid waste	
bottom liner	
biogas	
leachate collection system	

18.2. Incineration of garbage

After landfilling, incineration is the second common way of handling waste. Incineration means the oxidation of waste materials to simple mineral products such as carbon dioxide and water by burning under controlled conditions. The combustible components of garbage such as paper, plastics and wood provide fuel for the process. There are three general types of incineration plant burning municipal solid waste: moving grate, fixed grate, or fluidized bed incinerator.

Municipal incinerators produce energy, exhaust gases and a solid residue that amounts to about one-third of the initial weight of the waste. Bottom ash is the non-combustible material that collects at the bottom of the incinerator. This material must be deposited in a hazardous waste landfill or further processed in order to reduce the risk of concentrated contaminants (mainly heavy metals) being leached into the soil. This is usually achieved by the addition of adhesives or by vitrification. Fly ash is finely divided solid matter (10-15% of the total ash mass) that is transported with the exhaust gases. Fly ash is usually very toxic, since heavy metals, dioxins and furans readily condense onto small particles. Therefore, prevention of air pollution presents a great challenge and is crucially important in incineration. Typically, baghouse filters made from woven fabric and/or gas scrubbers are used for filtering out fly ash particles.

18.2.1. *Reading comprehension*

1. What is incineration?
2. What are the final gas products of incineration?
3. What are the types of solid residues produced during incineration?
4. What technological processes can be applied to reduce the risk of leachates from the bottom ash entering the soil?
5. Why can fly ash be a dangerous air pollutant?
6. Name some typical devices used for filtering the incinerator exhaust?

18.2.2. *New terms and expressions*

adhesive	spoiwo
aggregation	zlepianie, agregacja
baghouse filter	filtr workowy
bottom ash	popioły i żużle paleniskowe
burning	spalanie
carbon dioxide	dwutlenek węgla
challenge	wyzwanie
combustible	palny
condense	kondensować
contaminant	substancja skażająca
device	urządzenie
exhaust	wydech, wylot (gazów)
fibre (US fiber)	włókno
filter out	odfiltrowywać
fine	drobny
fixed grate	piec statyczny
fluidized bed	piec fluidalny
fly ash	popioły lotne
fuel	paliwo
hydrate	uwodnić, nawodnić
garbage	śmieci
exhaust gas	gaz odlotowy (gazowy produkt spalania)
hazardous waste landfill	składowisko odpadów niebezpiecznych
heavy metals	metale ciężkie
incineration	spopielanie
incinerator	spalarnia
initial	początkowy
leaching	wyciekanie
mineral	mineralny
moving grate	piec rusztowy
municipal	komunalny
non-combustible	niepalny
one-third	jedna trzecia

oxidation	utlenianie
pose	stwarzać, stanowić
prevent	zapobiegać
readily	z łatwością
residue	pozostałość
risk	ryzyko
scrubber	skruber, płuczka
vitrification	witryfikacja, zeszklenie
woven fabric	tkanina

18.2.3. *Exercises*

1. Match the appropriate phrases

addition of adhesives

air pollution device

bottom ash

combustible components of waste

dioxins, furans and heavy metals

incineration technologies

incinerator

small particles suspended in the gaseous exhaust

baghouse filter

immobilization of bottom ash

fluidized bed or moving grate

fly ash

furnace for burning waste

the main contaminants emitted during incineration

paper, organic matter, plastics

the solid residue collected at the bottom of the incinerator

2. Choose the appropriate expressions

Incineration of waste is a thermal **aggregation / oxidation** process leading to the production of energy and **significant / insignificant** waste reduction. In the incinerator, waste is **mineralized / hydrated** to CO_2 and H_2O. However, some **organic / inorganic** contaminants such as dioxins and PAHs are also emitted during this process. These compounds readily condense on the particles of **bottom ash / fly ash**. Installing **woven / glass fibre** filters prevents air pollution by incineration products.

3. Questions and problems

a. Compare landfilling and incineration by listing the advantages and disadvantages of both technologies.
b. Explain the difference between moving grate and fluidized bed incinerators.
c. Give specific examples of waste that may be incinerated with a low risk of toxic emissions and those that pose such a risk while being incinerated.

18.3. Reuse and recycling

The basic principle of modern waste management is to avoid the production of waste. Recycling is an important way to minimize waste production. Recycling is defined as closing the flow of any material within its lifetime. The cycle may be closed at various levels. We can reuse goods as such, e.g. by collecting, cleaning and then refilling glass bottles. But the recycling of materials is more common, for example recycling the aluminium contained in cans or the lead from lead-acid accumulators. Closure also occurs during the production process, where manufactured waste is fed back at a specified material-processing step. It is critical for the quality of the final product that recycled waste is sufficiently pure and well separated from other types of waste. Therefore, the proper segregation of waste prior to recycling is very important.

Suitability for recycling varies significantly with the type of material. Generally, materials from process streams are fully recyclable because they are the same materials used in the manufacturing operation. Recycled materials from post-consumer sources may vary in their composition and are frequently applicable only to uses requiring a lower quality. This process is called down-cycling or cascading. A typical example is the recycling of paper; but as the cellulose fibres in paper gradually wear down, this recycling is limited to just a few cycles. The chain usually goes from high quality paper, through newspaper to cardboard. The chain ends when the material is used for energy production through combustion.

18.3.1. *Reading comprehension*

1. What is the most general definition of recycling?
2. What is a necessary condition for successful recycling?
3. What types of materials are most suitable for recycling?
4. Why are materials from post-consumer sources less attractive to manufacturers?
5. What is meant by down-cycling?
6. When does the recycling cascade end in the case of the reuse of paper?

18.3.2. *New terms and expressions*

adequate	odpowiedni, stosowny, właściwy
aluminium can	puszka aluminiowa
avoid	unikać, zapobiegać
bin	pojemnik (na śmieci)
cardboard	karton, tektura
closure	zamknięcie
collect	zbierać
combustion	spalanie (w spalarni)
compost	kompost, kompostować
crate	skrzynka
de-ink	usuwać farbę drukarską
down-cycling (cascading)	kaskadowy (kolejne etapy recyklingu)
feed back	ponownie zasilić
fibre (US fiber)	włókno
flow	przepływ
lead-acid accumulator	bateria (akumulator) kwasowo-ołowiowa
lifetime	czas życia
manufacturing operation	proces produkcyjny
material processing	obróbka materiałów

melt	topnieć
newspaper	papier gazetowy (gazeta)
post-consumer	poużytkowy
prior	przed
process stream	strumień materiałowy
recyclable	nadający się do odzysku
recycling	recykling, recyrkulacja
refill	ponownie napełnić
reprocess	ponownie przetworzyć
reshape	ponownie nadać kształt
segregation	segregacja, sortowanie
separate	oddzielić
shred	rozdrabniać, rozdzierać na strzępy
sufficiently	odpowiednio, wydajnie
waste management	gospodarka odpadami
wearing	zużywanie

18.3.3. *Exercises*

1. Match the appropriate waste to the listed recycling methods and describe them briefly. Give examples of applications of recycled products


1


2


3


4


5

Recycling method	**Waste no.**	**Description of the process and the application of the recycled materials**
Reprocessing		Shredding, melting and reshaping of used polymeric materials to new products. Reprocessed PE can be used for manufacturing carrier bags, rubbish bins and bags, bottle crates, etc.
Shredding and de-inking		
Composting		
Washing and refilling		
Remelting		

18.4. Hazardous waste

Any waste or combination of wastes posing a substantial present or potential hazard to human health or living organisms is classified as hazardous waste. Common types of hazardous waste include materials that may be toxic, ignitable, corrosive, reactive or radioactive. They are usually non-degradable, persistent in nature and may cause detrimental cumulative effects.

The management of hazardous waste consists of a multistep strategy starting from source reduction during production through recycling and reuse whenever suitable, up to the final treatment and disposal. Treatment of hazardous waste requires more elaborate technologies than those used for municipal waste. In the case of disposal, waste burial must take place in properly designed landfills, where the materials are grouped according to their physical and chemical characteristics so that incompatible materials are not placed near each other. In the case of incineration, great care is taken to ensure that the material is completely destroyed and that emissions are under full control. Rotary kiln, cement kiln and liquid injection installations are examples of toxic waste incinerators.

18.4.1. *Reading comprehension*

1. What is hazardous waste?
2. What are the most common features of hazardous waste?
3. What are the main elements of a hazardous waste management strategy?
4. How does the treatment of hazardous waste differ from the treatment of municipal solid waste?
5. What types of incinerators are used for the combustion of hazardous waste?

18.4.2. *New terms and expressions*

agriculture	rolnictwo
burial	pogrzebanie, zakopanie
cement kiln	piec cementowy
combination	kombinacja
corrosive	korozyjny
cumulative	kumulacyjny
design	projekt, projektowanie

require	wymagać
expired	przeterminowany
destroy	zniszczyć
detrimental	szkodliwy
disposal	składowanie
elaborate	wymyślny, złożony, rozbudowany
hazardous waste	odpady niebezpieczne
ignitable	zapalny
incompatible	niepasujący
liquid injection incinerator	spalarnia z wtryskiem cieczy
management	zarządzanie, gospodarka
manager	kierownik, menadżer
medical care	służba zdrowia
multistep	wielostopniowy
non-degradable	niedegradowalny
persistent	trwały, uciążliwy
pose	stanowić (tylko w tym kontekście)
radioactive	radioaktywny, promieniotwórczy
reactive	reaktywny
rotary kiln	piec obrotowy rurowy
source reduction	zmniejszanie u źródła
storage	magazynowanie
substantial	znaczny, pokaźny
suitable	pasujący, odpowiedni
toxic	toksyczny
treatment	traktowanie, obchodzenie się

18.4.3. *Exercises*

1. Indicate which statements are true (T) and which are false (F).

a.	It is enough that waste is toxic to classify it as hazardous.	T / F
b.	MSW can contain hazardous waste.	T / F
c.	The classification of hazardous waste in Poland differs from that used in other EU countries.	T / F
d.	MSW landfills may accept hazardous waste under special agreements between waste producer and landfill manager.	T / F
e.	Expired pharmaceuticals, cadmium batteries and mercury thermometers are typical examples of household-produced hazardous waste.	T / F
f.	Cement kiln installations can be used for toxic waste incineration.	T / F
g.	Hazardous waste should be processed by certified companies only.	T / F

2. List examples of hazardous waste produced in:

Medical care ……………………………………………………………………………….

Agriculture ………………………………………………………………………………..

Mechanical utilities ……………………………………………………………………….

Energy storage …………………………………………………………………………….

Light emitters ……………………………………………………………………………..

MSW incineration …………………………………………………………………………

Industrial chemical synthesis ……………………………………………………......…

The household ..…………………………………………………………………………..

19. Sustaining the Atmosphere for Life

19.1. Depletion of the ozone layer

Ozone plays a crucial protective role in that it absorbs harmful ultraviolet radiation in the atmosphere. It is a natural shield that protects living organisms on the Earth from the effects of excessive amounts of such radiation. Any substantial reduction of stratospheric ozone may severely threaten nearly all forms of life.

In the stratosphere, ozone is produced by the following sequence of reactions:

$$O_2 + h\nu \rightarrow O + O$$

$$O + O_2 + M \rightarrow O_3 + M^* \quad ,$$

where M is another molecule, usually nitrogen or oxygen, which absorbs the excess energy given off by the reaction. Absorption of a UV photon results in the decomposition of the ozone molecule to molecular and atomic oxygen, both in an excited state. Most of these decomposition products react again to re-form ozone. The ozone production – destruction cycle is called the Chapman mechanism.

In the 1960s it was realized that some other mechanisms of ozone destruction were operative in the stratosphere, in addition to the Chapman process. A number of natural and anthropogenic chemicals act as catalysts for ozone destruction, including NO, NO_2, $HO^\cdot$, $HOO^\cdot$, ClO, Cl, Br and BrO. Chlorine is thought to be the principal culprit in current stratospheric ozone depletion. It is generated by the photochemical decomposition of synthetic chlorine-containing organic chemicals emitted into the atmosphere from anthropogenic sources. The recent increase in stratospheric chlorine is attributed primarily to the use and release of chlorofluorocarbons, chemicals consisting of carbon, fluorine and chlorine, commonly known as CFCs. For years CFCs were used as coolants and propellants, which resulted in increased emissions of these compounds to the atmosphere. Since 1990s, most CFCs have been classified as ozone-depleting compounds and are now banned by international agreements. In 1995 Sherwood Rowland, Mario Molina and Paul Crutzen were awarded the Nobel Prize in Chemistry for their explanation of atmospheric ozone depletion.

19.1.1. *Reading comprehension*

1. What is the role of ozone in the upper atmosphere?
2. How are ozone molecules formed in the stratosphere?
3. What happens after an ozone molecule has absorbed a UV photon?
4. What is meant by the Chapman mechanism (cycle)?
5. Which anthropogenic catalysts can accelerate ozone depletion?
6. Why do CFCs cause depletion of the ozone layer?

19.1.2. *New terms and expressions*

altitude	wysokość
artificial	sztuczny
attribute	przypisać
ban	zabronić, zakazać
catalyst	katalizator
chlorofluorocarbons	chlorofluorowęglowodory (freony)
coolant	czynnik chłodzący, chłodziwo
crucial	zasadniczy, istotny (w tym kontekście)
decomposition	rozpad
depletion	zubożenie
disappear	znikać
excess	nadmiar
excessive	nadmierny
excited state	stan wzbudzony
free radical	wolny rodnik
fuel	paliwo
harmful	szkodliwy
Nobel Prize	Nagroda Nobla
operate	działać, zachodzić
ozone	ozon
ozone depleting compounds	substancje zubożające warstwę ozonową
ozone layer	warstwa ozonowa
propellant	gaz wyrzutowy, propelent
protective	ochronny
re-form	tworzyć ponownie

release	wprowadzenie
rocket	rakieta
severely	poważnie, dotkliwie
shield	tarcza, osłona
stratospheric	stratosferyczny
substantial	istotny
threaten	zagrozić
ubiquitous	powszechny, wszędobylski
ultraviolet (UV) radiation	promieniowanie nadfioletowe

19.1.3. *Exercises*

1. Indicate which statements are true (T) and which are false (F).

a.	Ozone is formed by the reaction of two molecules of oxygen.	T / F
b.	Stratospheric ozone protects living organisms from excessive UV radiation.	T / F
c.	The units used for measuring the amount of ozone in the atmosphere are called Dobson units.	T / F
d.	The ozone layer may disappear seasonally above polar regions.	T / F
e.	The emission of bromine-containing compounds is the main reason for anthropogenic ozone destruction.	T / F
f.	CFCs are ubiquitously present in the atmosphere because they were used as rocket fuel.	T / F

2. Questions and problems

a. What are the altitude ranges of the troposphere and stratosphere?

b. Explain the difference between stratospheric and tropospheric ozone from the point of view of hazards to human health.

c. Define the term ‘free radical’ and give two examples relevant to the chemistry of the stratosphere.

d. What ranges of UV radiation (wavelength in nm) are filtered off by O_2 and by O_3? Would there be any danger to human health if this radiation were not stopped?

e. Explain the term "excited state".

19.2. Acid precipitation and photochemical smog

Acid rain is one of the most serious environmental problems facing many regions of the world. This term refers to precipitation that is significantly more acidic than natural rain. The excessive acidity of rainwater is caused by the presence of sulphuric acid and nitric acid, both of which are strong acids. They are formed in the atmosphere during the transport of air masses that contain primary pollutants such as sulphur dioxide and nitrogen oxides. The main anthropogenic source of SO_2 is the combustion of coal, which usually contains 1-6% of sulphur, depending on its origin. Since primary pollutants travel long distances in the atmosphere, acid rain may affect countries that do not necessarily release them into the atmosphere. For example, a significant fraction of the acid precipitation in Scandinavian countries originates in Poland, eastern Germany or the Czech Republic.

Acid rain devastates nature through its direct impact on plants but also through the deterioration of soils. The latter is caused by the leaching of some plant nutrients, such as potassium, calcium and magnesium ions, which are exchanged for hydrogen ions in an acidic medium.

Smog is the other main environmental problem related to ground level pollution. The word ‘smog’ was originally coined from a combination of ‘smoke’ and ‘fog’, but the formation of modern-day, photochemical smog involves hundreds of reactions in which chemicals (primary pollutants) such as nitric oxide and volatile organic compounds (VOC) participate, which are often present in excess in the urban atmosphere. In the presence of oxygen and sunshine (enhancing the formation of very reactive free radicals) they are transformed into a harmful mixture of ozone, nitric acid and various organics. Nitric oxide is the most important reactant in any photochemical smog episode. It is produced whenever a fuel is burned in air with a hot flame. Therefore, one of the most significant anthropogenic sources of NO is motor vehicle traffic.

19.2.1. *Reading comprehension*

1. What are the main components of acid rain?
2. What primary pollutants contribute to the formation of acid rain?
3. What are the main sources of atmospheric SO_2 and NO?
4. How does acid precipitation cause soils to deteriorate?
5. What are the main constituents (primary and secondary) of photochemical smog?
6. What is the role of sunshine in the formation of photochemical smog?

19.2.2. *New terms and expressions*

acid precipitation	kwaśny opad
acidic	kwaśny
affect	wywierać wpływ
air masses	masy powietrza
calcium	wapń
coal	węgiel
coined	wymyślone (o nowym słowie)
combustion	spalanie
corrosive	niszczący, korozyjny, żrący
deterioration	degradacja, stopniowe niszczenie
devastate	dewastacja, zniszczenie
distance	odległość
enhance	wzmagać
exclude	wyłączyć, usunąć
flame	płomień
fog	mgła
free radical	wolny rodnik
ground level	warstwa przyziemna
harmful	szkodliwy
leach	wypłukiwać, wymywać
liberation	uwolnienie
limestone	wapień, kamień wapienny
magnesium	magnez
marble	marmur

motor vehicle traffic	ruch samochodowy
nitric acid	kwas azotowy
nitric oxide	tlenek azotu
nitrogen oxides	tlenki azotu
nutrient	biogen, składnik odżywczy
origin	pochodzenie
oxygen	tlen
photochemical smog	smog fotochemiczny
potassium	potas
primary pollutant	zanieczyszczenie pierwotne
precursor	prekursor
predominant	przeważający
pyrite (iron disulphide)	piryt (dwusiarczek żelaza, FeS_2)
reactant	reagent
reaction rate	szybkość reakcji
Scandinavian countries	kraje skandynawskie
smoke	dym
sulphur	siarka
sulphur dioxide	dwutlenek siarki
sulphuric acid	kwas siarkowy
sunshine	słoneczna pogoda
thereupon	w rezultacie
urban	miejski
volatile organic compounds VOC	lotne zanieczyszczenia organiczne LZO

19.2.3. *Exercises*

1. Match the appropriate phrases

acid rain

combustion of coal

leaching nutrients

liberation of Al^{3+} from soils

Los Angeles / London

NO + VOC

pyrite

smog

sulphuric and nitric acid

volatile organic compounds

VOC

cities where smog was defined for the first time

deterioration of soils

indirect phytotoxic effect of acid rain

mineral form of sulphur in the fossil fuels

precipitation of low pH

predominant acids in acid rain

primary pollutants in smog

smoke + fog

anthropogenic source of SO_2

2. Choose the appropriate expressions.

Sulphuric / hydrochloric acid is the main component of the acid precipitation from polluted air. The main sulphur precursors of acid rain are most often formed during **fossil fuel combustion / waste incineration**. Acid rain may be characterized as a **point / dispersed** type of pollution. Deterioration of soil occurs when its pH is significantly **raised / lowered** as a result of acid precipitation. The necessary condition for photochemical smog formation is **sunshine / darkness**, because involved reactions take place. **London / Warsaw** was the first European city where smog was observed and described.

3. Questions and problems

a. Explain the chemistry involved in the corrosive effect of acid rain on buildings and monuments of limestone or marble.

b. Explain why free radicals enhance the rate of reactions associated with smog.

c. Discuss the technical possibilities of reducing acid rain precursors (e.g. eliminating sulphur from the fossil fuels).

19.3. The greenhouse effect and climate change

The terms 'greenhouse effect' and 'global warming' refer to the increase in the average global temperature as a result of the build-up of 'greenhouse gases' in the atmosphere. Greenhouse gases, including the infamous carbon dioxide, are substances that allow incoming solar radiant energy to penetrate to the Earth’s surface while absorbing the infrared radiation emitted from it. The levels of these gases in the atmosphere have been increasing rapidly in recent decades. Although there are uncertainties associated with global warming, several aspects pertaining to the phenomenon are well established.

It is known that along with water vapour, CO_2 and gases such as CH_4 and N_2O are primarily responsible for the absorption of the infrared energy re-emitted by the Earth. Carbon dioxide traps about half the atmospheric heat retained by greenhouse gases. It is produced mainly by the combustion of fossil fuels and by deforestation accompanied by the burning and biodegradation of biomass. Current evidence suggests that changes in the atmospheric carbon dioxide level will substantially alter the Earth’s climate through the greenhouse effect. With current trends, it is likely that during this century global CO_2 levels will reach double the pre-industrial level, which may raise the Earth’s mean surface temperature by as much as $4^{o}C$.

Such a dramatic climate change may lead to potentially disastrous situations: the rapid shrinking of the Earth’s ice cover; sea levels rising to such an extent that they may engulf Pacific islands; extreme weather events, including heavy storms, hurricanes and increased precipitation. Moreover, an increase in the temperature may also disrupt the seasonal cycles. Shorter winter periods may affect the life of many plant species and may increase the occurrence of mosquito-borne diseases in higher latitudes. It is also predicted that climate change will lead to drought in many areas as a result of the consequent water shortage, further reducing vegetation, and finally to soil erosion and desertification.

19.3.1. *Reading comprehension*

1. Explain in simple terms what the greenhouse effect is.
2. Why are greenhouse gases able to retain heat near the Earth's surface?
3. What are the main greenhouse gases and what are their sources?
4. What is the current trend of CO_2 emissions leading to?
5. What are the main possible consequences of global warming?

19.3.2. *New terms and expressions*

absorption	absorpcja, pochłanianie
accompany	towarzyszyć
alter	zmieniać, modyfikować, różnić
altitude	wysokość
behaviour (US behavior)	zachowanie
breathe	oddychać
build-up	nagromadzenie, spiętrzenie
century	wiek
current	obecny, współczesny
decade	dekada, dziesięciolecie
deforestation	wylesianie
desertification	pustynnienie
disturb	zaburzyć, przeszkodzić
disastrous	zgubny, katastroficzny
dramatic	dramatyczny, gwałtowny
drought	susza
engulf	pochłaniać
evidence	dowód
fossil fuel	paliwo kopalne
global warming	globalne ocieplenie
greenhouse	szklarnia, cieplarnia
greenhouse effect	efekt cieplarniany
greenhouse gases	gazy cieplarniane
hurricane	huragan
ice cover	pokrywa lodowa
incoming	przychodzący, wchodzący

infamous	niesławny, cieszący się złą sławą
infrared radiation	promieniowanie podczerwone
mosquito-borne diseases	choroby roznoszone przez komary
ordinary	zwykły, kolokwialny
pertain	odnosić się do
phenomenon	zjawisko
prediction	prognoza, przewidywanie
pre-industrial	preindustrialny
rapid	gwałtowny
re-absorbtion	reabsorpcja
re-emitted	reemisja
refer (to)	odnosić się (do)
shortage	brak, niedobór
shrinking	kurczenie się
solar radiant energy	energia promieniowania słonecznego
substantially	duży, ważny, poważny
threaten	grozić, zagrażać
trap	wychwytywać, więzić
uncertainty	niepewność

19.3.3. *Exercises*

1. Fill in the blanks

Carbon dioxide is the main ………………. gas responsible for about half of the ……………… effect. Other examples of such gases are ………………………, ………………… and ……………………. . The re-absorption of ……………….. radiation emitted from the Earth is believed to be the main reason for ………….. warming. It is being predicted that this process will lead to ………… weather events such as storms, but also to the …………….. of large areas as a result of drought and soil erosion. It is also predicted that in …………… latitude regions the incidence of ……………….. diseases will increase significantly.

2. Indicate which statements are true (T) and which are false (F).

a. The main gases responsible for the greenhouse effect are carbon oxide and nitric oxide. T / F

b. Greenhouse gases re-absorb ultraviolet radiation emitted by the Earth. T / F

c. Anthropogenic carbon dioxide is primarily produced by the combustion of fossil fuels. T / F

d. A significant part of CO_2 in the atmosphere is emitted by humans while breathing. T / F

e. The increased rate at which the Earth's ice cover is melting may be a serious threat to Pacific islands. T / F

19.4. Particulate matter in air

Smoke in vehicle exhausts and from industrial processes consists largely of particulate matter. Particulates are suspensions in air of tiny solid or liquid particles, usually individually invisible to the unaided human eye. Apart from smoke, anthropogenic particulates include those from the wear and tear of vehicle tyres and brakes, as well as dust from metal smelting. The incomplete combustion of fossil fuels such as coal, oil, petrol and diesel fuel produces fine soot particles, which are usually crystallites of carbon.

Motor vehicle traffic is one of the major sources of carbon-based atmospheric particulates. The PM index is a measure of the concentration of particles suspended in air, used in air quality monitoring. PM gives the mass of particulate matter present in a given volume of air and is usually expressed in $\mu g\ m^{-3}$. The PM_{10} parameter refers to the total concentration of particles with a diameter of less than 10 µm. These are also called inhalable particles, since they can be breathed into the lungs. A typical value of PM_{10} in urban areas is 20 – 30 $\mu g\ m^{-3}$. The $PM_{2.5}$ index, also known as the respirable fraction, refers to particles smaller than 2.5 µm in diameter, which are able to penetrate to the gas exchange area deep in the lungs.

The adverse health effects of particulate matter is due not only to the particles themselves, but also to various substances adsorbed on their surfaces. Particulates act as carriers for aromatic and aliphatic hydrocarbons, chlorinated organics as well as heavy metals.

19.4.1. *Reading comprehension*

1. What is particulate matter?
2. What are the main sources of anthropogenic particulates in air?
3. What are the PM indices and which particle sizes are usually taken into account?
4. What is the difference between the inhalable and respirable fractions?
5. What types of contaminants may be present on the surface of particles suspended in air?

19.4.2. *New terms and expressions*

anthropogenic	antropogeniczny
brake	hamulec
breath; breathe	oddech; oddychać
carrier	nośnik
crystallites	kryształki, krystality
diameter	średnica, rozmiar
dust	kurz
exhaust	wydech, wylot
fine	drobny
fossil fuels	paliwa kopalne
incomplete	niecałkowity
inhalable fraction	frakcja wdychana
invisible	niewidzialny
lungs	płuca
motor vehicle traffic	ruch samochodowy
particulate	pyłowy, zawiesina pyłu
PM index	indeks pyłu zawieszonego
respirable fraction	frakcja respirabilna
smelting	stapianie, hutnictwo
smoke	dym
soot	sadza

suspend	zawiesić
tiny	maleńki
tyre (US tire)	opona
urban areas	obszary miejskie
vehicle	pojazd
wear and tear	ścieranie, zużycie

19.4.3. *Exercises*

1. Fill in the blanks

The main …………………. source of particulates in the atmosphere is ……. traffic, the wear and tear of ……….…. and the incomplete ………….. of diesel fuel. The metal ………… industry also contributes to the total particulate emissions. The PM_{10} index refers to the ……………….. of all ……………. in the air having diameters less than 10 µm. The ………. fraction is represented by the $PM_{2.5}$ index. This fraction contains particulates able to ………….. deep into the ………….. . Suspended particles are very good adsorbents for a variety of ……………. chemicals, including ………. metals and volatile organic ……………. .

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