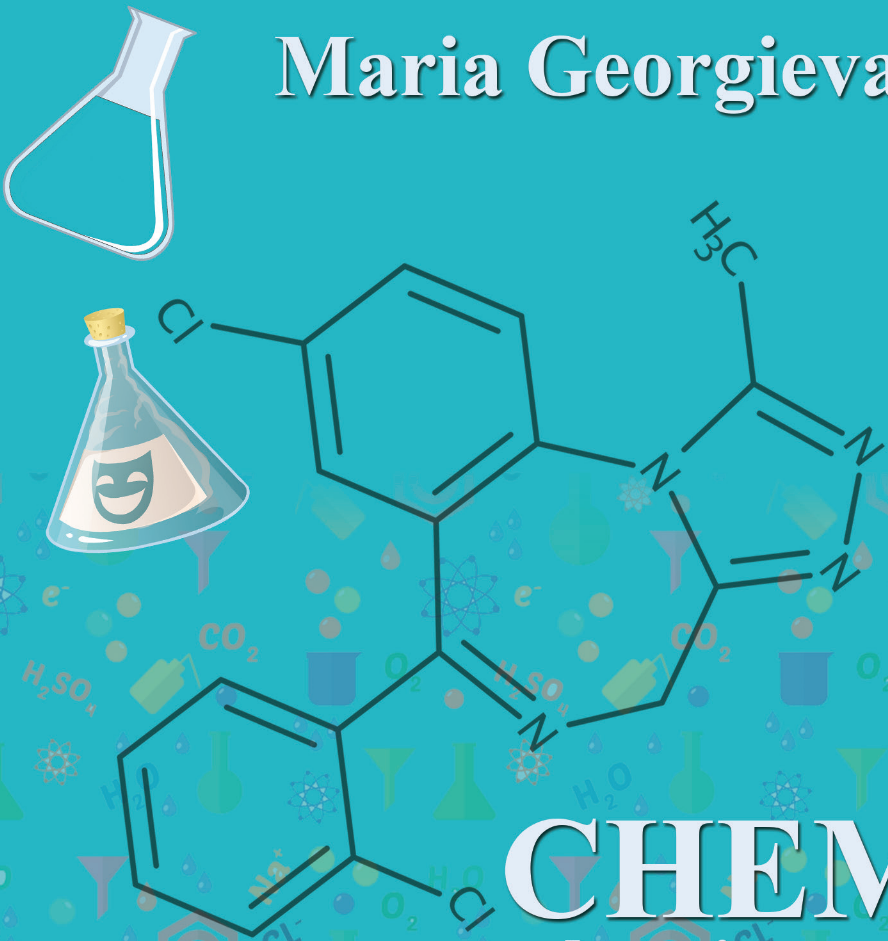
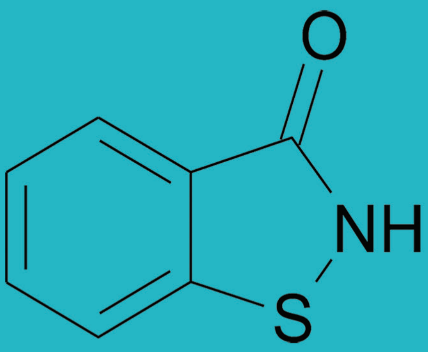
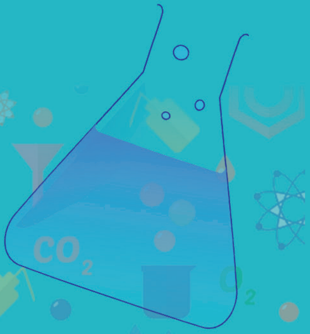




Maria Georgieva



CHEMISTRY

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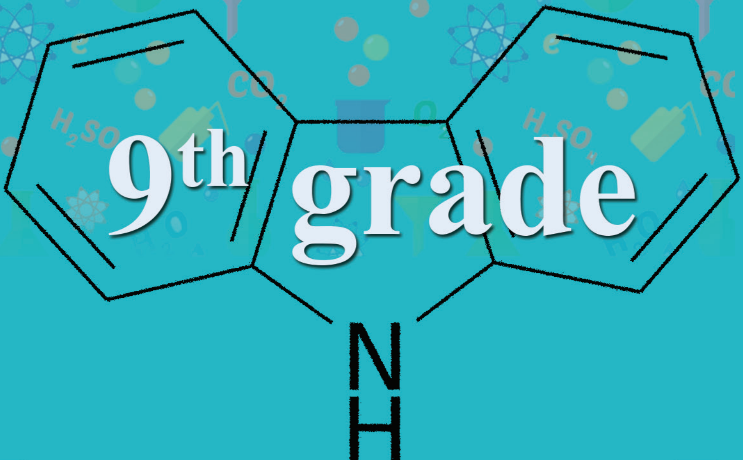

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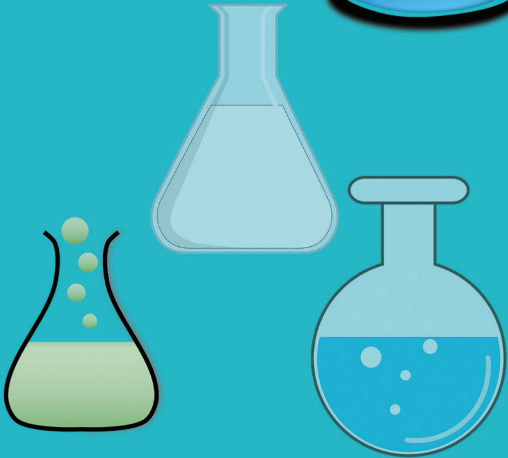

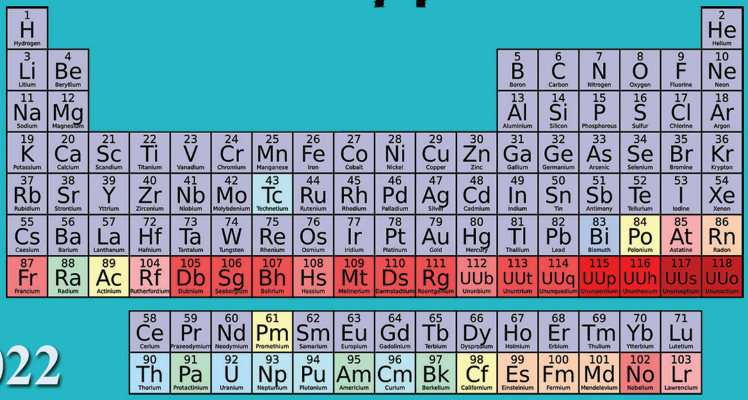

1 H Hydrogen																	2 He Helium
3 Li Litium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminium	14 Si Silicon	15 P Phosphorous	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenium	43 Tc Technetium	44 Ru Rutenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Caesium	56 Ba Barium	57 La Lanthanum	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89 Ac Actinium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 UUb Ununbium	113 UUt Ununtrium	114 UUq Ununquadium	115 UUp Ununpentium	116 UUh Ununhexium	117 UUs Ununseptium	118 UUo Ununoctium

58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

2022

МИНИСТЕРСТВО НА ОБРАЗОВАНИЕТО И НАУКАТА

НАЦИОНАЛНА ПРОГРАМА
„Учебници, учебни комплекти и учебни помагала“

МОДУЛ
„Разработване на учебни помагала на чужд език за обучение
по общообразователни учебни предмети“

9. КЛАС

Химия и опазване на околната среда на английски език

Учебно помагало
Разработено от авторски екип
към Първа езикова гимназия – Варна

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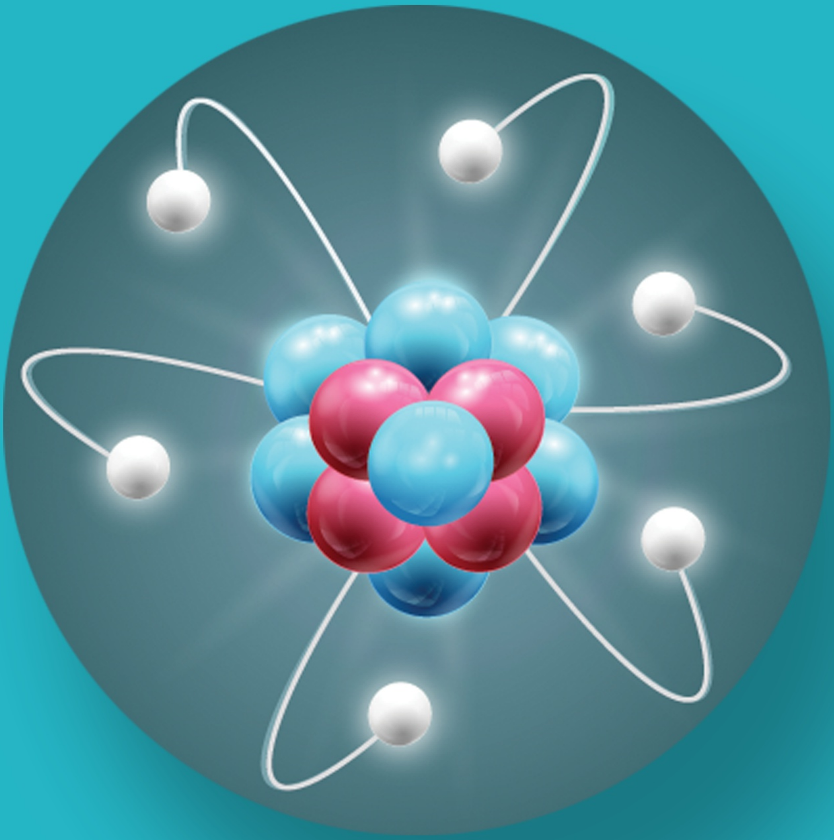
Structure of matter



Structure of matter – introduction

Chemistry is a really important and interesting science. It's necessary to know more about the chemical compounds and processes because they are everywhere around us. The ancient Greeks were first who were interested in knowing more about the matter and tried to explain the chemical changes. In 400 BC, Democritus proclaims that the matter is composed of atoms (first used the term *atomos* which in Greek means indivisible), and it is the simplest unit of the matter. A hundred years later, Aristotle said that there is only four elements earth, air, fire and water which has only four properties hot, cold, dry and wet. Until the end of 17th century the chemical researches were led by alchemists who were often considered wizards because they wanted to create the elixir of life and to turn cheap metals into gold. After the disproving Aristotle's theory by Robert Boyle, the era of traditional chemistry has begun. All the philosophers' theories were disproved and in 1804 Dalton publishes his *Atomic theory* in which he claims that each element has atoms, all the compounds are the result of chemical reactions in which atoms are reorganized and bonded to each other. This theory has made chemistry more systematic and since then it began to develop and become the chemistry we know today. Chronological review of development of atomic structure models and the scientists who work on them you can find on figure 1.

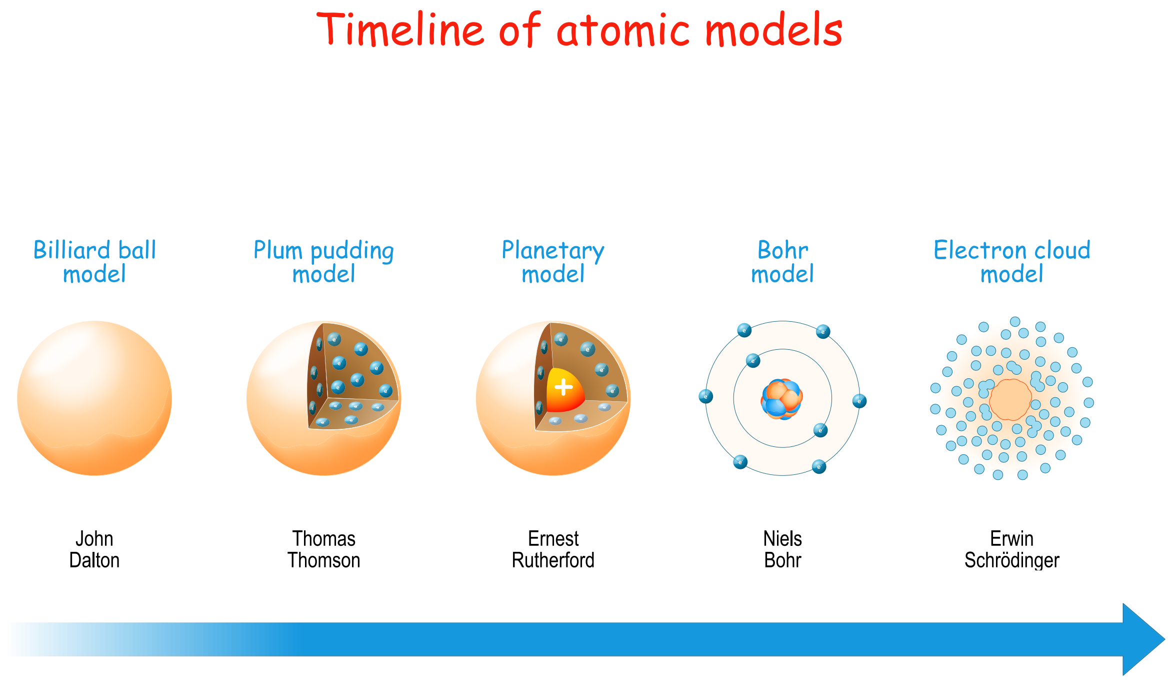


Figure 1

Atomic structure

1

Atom consists of a tiny nucleus and electrons that surround it arranged in an electron shell. The nucleus contains protons (p $^+$) which are positively charged and equal to the charge of the electrons; that's why atoms are electrically neutral, and neutrons (n ^{0}) with the same mass as protons but without charge. Protons and neutrons are held together by a nuclear force. The amazing thing is nucleus has small size compared to the size of the atom but with a great density and atom's mass is concentrated in the nucleus. There is a relationship between the number of the protons in the nucleus and the atomic number of the chemical element (Z), they are equal. The atomic number shows the position of each element in the Periodic Table.

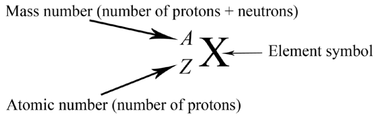


Figure 2

For example: Magnesium has 12 protons which means its atomic number is 12 and the opposite if the atomic number is 12, we can say it has 12 protons.

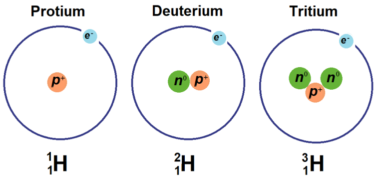


Figure 3

The sum of protons and neutrons in the nucleus is called mass number (A). The atomic number is written in front of the symbol of the element at the bottom left and the mass number is written at the top left. Figure 2.

The nuclear symbols of carbon, nitrogen and oxygen are

$$^{12}_{6}\mathrm{C} \quad ^{14}_{7}\mathrm{N} \quad ^{16}_{8}\mathrm{O}$$

Atoms with the same number of protons but a different number of neutrons are called isotopes. All isotopes can be represented by a nuclear symbol like the one written above. For example, hydrogen has three isotopes and we can represent them as it's shown on figure 3.

Key terms

- atom
- nucleus
- proton
- neutron
- nuclear force
- atomic number
- mass number
- isotopes

Solve the problems below

Problem 1.

Complete the text using the words

Nucleus, positively, neutrons, chemical element, protons, same, atomic number, number of neutrons, mass number, position, isotopes, electron shell, nuclear force.

The atom consists of……………….and ……….............. Nuclei are made of…………………. charged …………………… and electrically neutral ………………………held together by a ……………………………….. A …………………………………… is made up of atoms with the…………………………number of protons. This number is called …………………………… (Z) and it determines the.............................. of each element in the Periodic Table. The .... (A) is a sum of the number of protons and the .... If two atoms have different mass numbers but the same atomic number, we call them ....

Problem 2. Fill in the table

Element	Chemical symbol	Atomic number	Number of protons	Number of neutrons	Mass number
	N				14
		11		12	
Aluminum		13			27
	O		8		16

Problem 3

Write the symbol for the atoms that have (a) Z=9, A=19; (b) Z= 19, A=40; (c) Z=15, A= 31; (d) Z=16, A= 32; (e) Z=35, A=79. How many protons and neutrons each atom have? Represent them with a nuclear symbol.

Solution: a) The atomic number 9 means the atom has 9 protons. It's called fluorine and the symbol is F. Since the atom has 9 protons, it must have 9 electrons so it can be electrically neutral. The mass number is 19 which means the number of neutrons is 10. The nuclear symbol is:

$$^{19}_{9}\mathrm{F}$$

b)...
....
....
c)...
....
....
d)...
....
....
e)...
....
....

Electron shell

2

The chemical properties of an element are defined by the structure of its electron shell. It is important to know the way the electron shell is built up because we can predict and explain the elements' properties.
Each atom's shell contains electrons. The most important properties of the electron are mass, charge, spin and energy. The electrons are particles with negative charge (e^-) and a really small mass (1/1837 from protons' mass). As we already know the number of electrons is equal to the number of protons because the atom is electro neutral.
According to Bohr's model (of the atomic structure), electrons are in constant motion around the nucleus and they have different energy. (Figure 1).

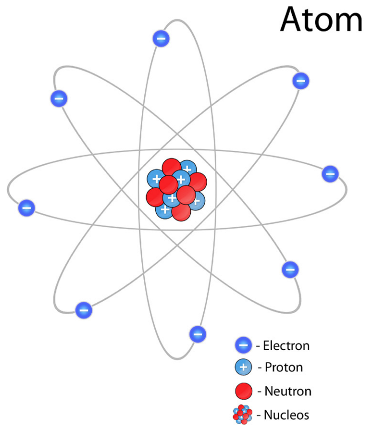


Figure 1

Spin is a magnetic property of the electron and it is usually denoted by an arrow pointing up (↑) or down (↓). Two electrons can have parallel or opposite spins. In the first case, the electrons are unpaired because they can't form an electron pair. Electron pair is formed from two electrons with opposite spins (↓↑).

Energy is a property that defines the way the electron shell is built. The electrons with a similar amount of energy form a shell. Each atom has a different number of electron shells. We can denote the electron shells in two different ways, with a number from 1 to 7 or with a capital Latin letter from K to Q. The shell closest to the nucleus has the lowest energy and the farthest shell of an atom called the outermost shell, has the highest energy. The number of electrons in the shell is not random. Each shell can have a maximum number of electrons $2n^2$ where n is the number of the shell (for example, if n=1, the max. amount of electrons for the first shell is $2.1^2 = 2$). The occupation of the electrons in the shell is called electron atomic structure and it's represented with an atom diagram. When building up the diagram we have to follow a few rules:

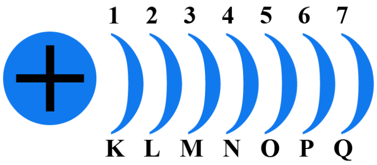


Figure 2

1. We start building up the electron shell from the shell with the smallest amount of energy to the highest amount of energy, i.e. from the first to the seventh (K shell → Q shell).
2. The first shell can have only two electrons (except Hydrogen which has only 1 electron). This shell is completed and stable when it contains two electrons with opposite spins (an electron pair).
3. The outermost shell can hold maximum eight electrons and it is stable (containing 4 electron pairs).
4. The electrons in the shell can form a pair or can be unpaired.

2 Electron shell

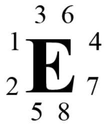


Figure 3

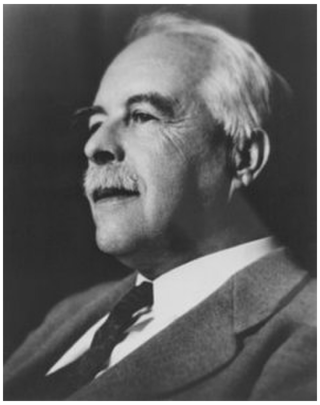


Figure 3
Gilbert N. Lewis

Key terms

- Electron
- electron shell
- mass
- negative charge
- spin, energy
- outermost shell
- valence electrons
- Lewis dot formula

As we said above, the chemical properties are defined by the electron shell and, to be precise, by the outermost electron shell. (As was mentioned above, the chemical properties are defined by the outermost electron shell.) The electrons in the outermost shell are called valence electrons. They can be single or paired. The electrons from the outermost electron shell are denoted by dots in the Lewis formulas. The Lewis formula is a dot formula where a pair of electrons is represented with two dots and the single electrons are represented with one dot, written around the symbol of the chemical element. The dots must be written in a specific position as it's shown on Figure 3.

In table 1 you can see the Lewis' diagrams for each element from the second period of the Periodic table.

	Group							
Period	I A	II A	III A	IV A	VA	VIA	VIIA	VIIIA
2	$\cdot\mathbf{Li}$	$:\mathbf{Be}$	$:\dot{\mathbf{B}}$	$:\dot{\mathbf{C}}\cdot$	$:\underset{\cdot}{\dot{\mathbf{N}}}\cdot$	$:\underset{\cdot}{\ddot{\mathbf{O}}}\cdot$	$:\underset{\cdot}{\ddot{\mathbf{F}}}:$	$:\underset{\cdot\cdot}{\ddot{\mathbf{Ne}}}:$

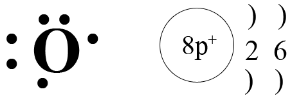
Solve the problems below

Problem 1. True or false

The chemical properties are defined by the number of the protons in the nucleus	T	F
Electrons with same amount of energy form an electron shell		
The outermost electron shell has the lowest energy		
The maximum number of electrons in each shell is $2n^2$, where n is the number of the shell		
The outermost shell is most stable if it contains 8 electrons		
Only electrons with parallel spin form electron pairs		

We find the valence electrons on the first shell		
Electrons from the last electron shell are represented with Bohr symbols		
The electron is a particle with positive charge		
First shell has maximum 2		

Problem 2. Draw the atom diagrams for the following atoms: Oxygen, Calcium, Sulfur, Sodium, Nitrogen and Chlorine and explain them following the example below. Write the Lewis symbol and how many single electrons and electron pairs do they have.
Example. Oxygen has Z = 8. Because the atom is electroneutral, it must have 8 protons in the nucleus and 8 electrons in the electron shell. Oxygen has 6 valence electrons in the last shell – two electron pairs and two single electrons. The diagram and the Lewis formula are



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Problem 3. Fill in the table

Elements	Symbol	Unpaired electrons	Electron pairs	Lewis symbol
Bromine	Br	1	3	$:\overset{\cdot\cdot}{\underset{\cdot}{\mathrm{Br}}}:$
Iodine				
Phosphorus				
Potassium				
Silicon				

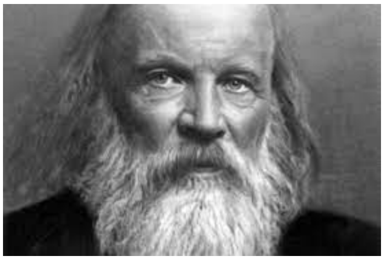
Find out more about particles

https://home.web.cern.ch/science/physics/standard-model

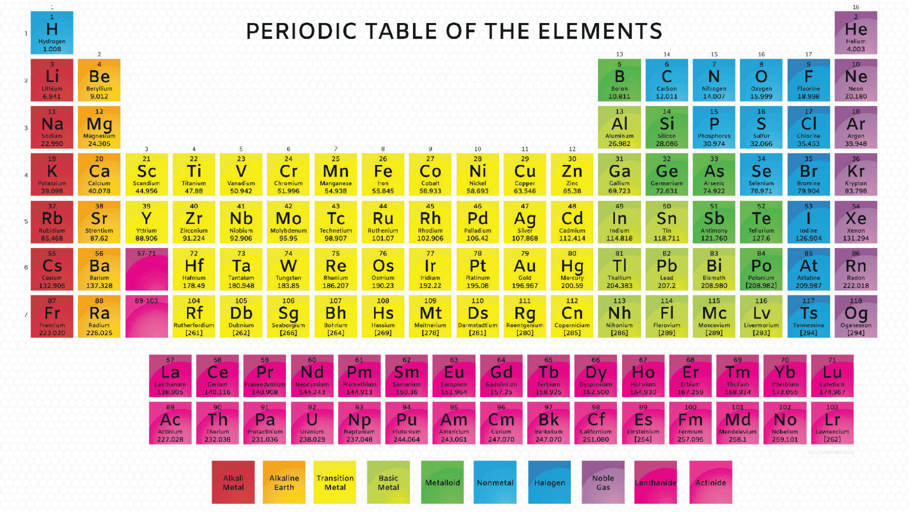
Periodic law and Periodic table

3

When you walk into a chemistry class, you see a large Periodic Table hanging on the wall. All of us, at some point, got scared of it because of all the elements and all the little letters that mean nothing to us at first sight. You may not have thought about it, but it is very important because it contains information that helps us determine the structure and properties of atoms and the properties of simple substances and chemical compounds, as well. Now, we will make a link between everything we said in the previous two lessons and the way the Periodic table is built up.



Dmitri Mendeleev



PERIODIC TABLE OF THE ELEMENTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 1.008																	2 He Helium 4.003
2	3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
3	11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798
5	37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294
6	55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
7	87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]

57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967
89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

Alkali Metal
Alkaline Earth
Transition Metal
Basic Metal
Metalloid
Nonmetal
Halogen
Noble Gas
Lanthanide
Actinide

Periodic Table

We can't talk about The Periodic table without mentioning the name of Dmitri Mendeleev. You've heard about him and you know he is a Russian chemist who was the first to arrange all known chemical elements in order of their increasing relative atomic mass. As the conception of atom's structure and electronic configuration developed, it became obvious that the properties of the atoms are periodic function of their atomic numbers. This is a relationship called Periodic law. The Periodic table is an arrangement of the atoms in order of increasing atomic numbers and it collects atoms with similar properties in vertical columns called groups. Except for columns, the Periodic table has rows, called periods. The periodic table have eight groups (A and B) and seven periods. If you understand the organization of the table, you won't need to memorize anything in it.

The numbers with which we denote them, show us two things: the number of electrons in the outermost shell and the number of shells in the electron shell.

Key terms

- Periodic law
- Periodic table
- Group
- Period
- Metals
- Nonmetals
- Metalloids
- Division line
- Atomic radius

Number of A group = Number of the valence electrons in the outermost shell

Elements in the same group of the periodic table have the same valence-electron configurations

Number of A group = Number of layers in the electron shell

Elements in the same period of the periodic table have the same number of shells.

Example Potassium has Z=19. We find it in 4nd period 1 A group. It means potassium has 4 shells and 1 valence electron in the outermost shell. Calcium has Z=20. We find it in 4th period 2 A group, so it has 4 shells and 2 valence electrons in the outermost shell.

The basic division of the simple substances of the chemical elements is into metals and nonmetals. The metals have tendency to lose electrons and form positive ion and nonmetals gain electrons and form negative ion. There is a division line in the periodic table called boron-astatine (B – At) line and many elements under certain circumstances exhibit metallic or nonmetallic properties. They are called metalloids. Each atom has atomic radius (R). This is the distance between the nucleus and the outermost shell. In the groups it increases because of weaker attraction between nucleus and outer electrons and the opposite in periods. That's why down the group metallic properties increase, in periods they decrease. In Figure 2, you can see how these properties change.

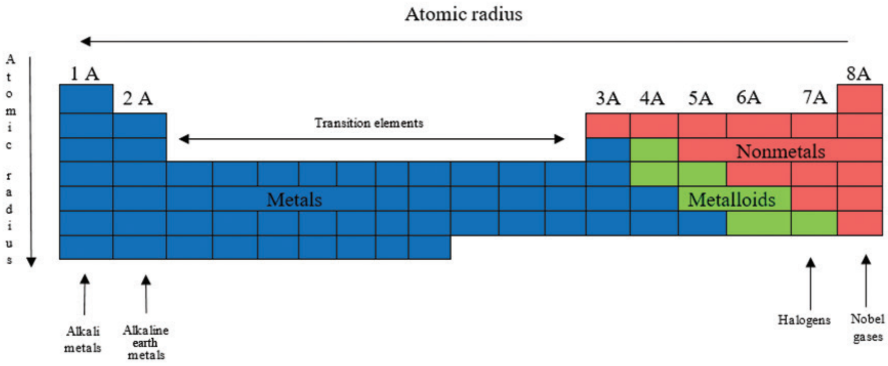
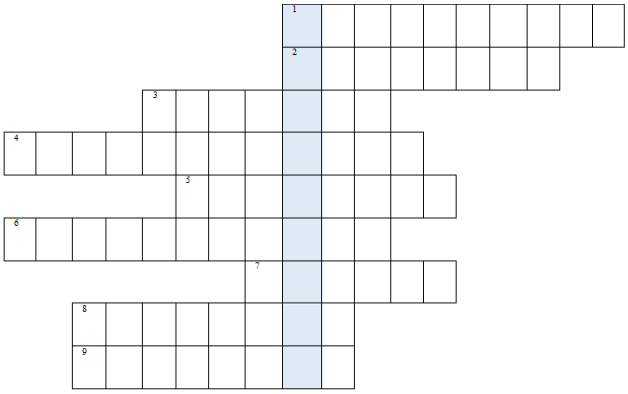


Figure 2

Periodic law and Periodic table 3

Solve the problems below

Problem 1. Nuclear chemistry crossword



ACROSS
1. Total number of protons and neutrons in the nucleus.
2. Particles orbiting the nucleus.
3. The electrons in the outermost shell.
4. The distance between nucleus and outermost shell.
5. Elements on the upper right hand corner.
6. The statement defining that the properties of the elements are periodic functions of their atomic numbers.
7. Elements on the lower left hand portion of the table.
8. Nuclei with the same number of protons but different number of neutrons.
9. Positively charged particle in the nucleus.

DOWN
1. The name of a great Russian chemist, who created the Periodic table.
* Find some interesting facts about him on the internet or in the library and share them with the class next time.

Problem 2. Arrange each of the atoms in the following groups in order of increasing atomic radius. What are their chemical properties – metals, nonmetals or metalloids?

1) Ca, Be, Ba …. < …. < ….
2) F, N, O …. < …. < ….
3) Cl, K, Al …. < …. < ….
4) Mg, Si, C …. < …. < ….

3 Periodic law and Periodic table

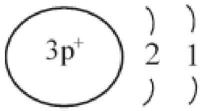
Problem 3. Relationships

3.1. Following the example, draw atoms' diagram and explain the relationship between atomic structure, place of the elements in the Periodic Table and chemical properties of the elements a) Z = 3 b) Z= 16 c) Z= 9 d) Z= 20

Example a). The element is Lithium (Li). It is in 1 A group, 2nd period so it must have 2 shells and 1 electron in the outermost shell. Lithium tend to lose an electron and form a positive ion which defines it as metal. Because the atomic number is 3, it must have 3 protons and 3 electrons. Atomic diagram is:

Lewis symbol is

·Li



b)…………………………………………………………………………

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b)…………………………………………………………………………

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d)…………………………………………………………………………

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3.2. Which elements would be the most likely to gain electrons and which element has the biggest atomic radius?

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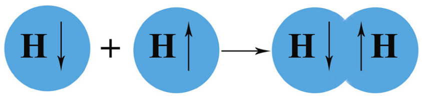
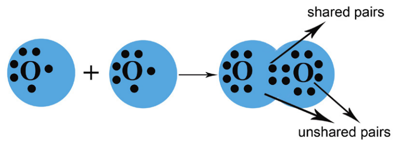
Types of chemical bonding 4

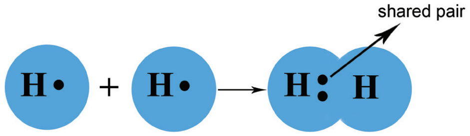
When we look at the periodic table, we see that there are 118 known chemical elements. This leads us to the question, can atoms exist isolated? The answer is no. Atoms have higher energy in the unbound state. When atoms react, their energy becomes lower and their electronic structure change, giving chemical bonds that hold them together. Because of the bonding, there are a large variety of chemical compounds. So, the main reason for atoms to react is lowering the energy. Here we will examine three types of chemical bonding and the way they are formed.

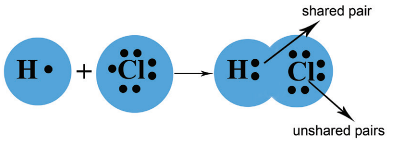
4.1. Covalent chemical bonding

The simplest compound is the molecule of hydrogen, H_2. The formula shows us we have two bonded hydrogen atoms. Hydrogen has 1 proton and 1 electron in the shell. When two atoms come close enough to each other, they form an electron pair with their unpaired electrons with opposite spins and that holds them together. Actually, it's an electrostatic attraction between two positive nuclei and two negative electrons. The formed pair is called shared pair. The Lewis structure can be used for denoting the structure of a molecule, as it's shown on the figures.







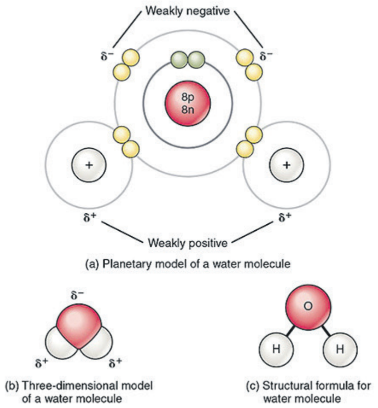


This type of bonding between two nonmetals which share one or more electron pairs is called covalent bond. There are different types of covalent bond.

One of the most important concepts in bonding is electronegativity. Electronegativity (χ) is the ability of the atom to attract the shared pair and it has tabulated values (see p. 18). Across the periods electronegativity increases. The larger the electronegativity of an element, the more strongly atom attracts the shared pair. (Figure 2).

According to electronegativity (χ) there are two types of covalent bonds: non-polar and polar.

➢ Atoms bonded with non-polar covalent bond have no differences in electronegativity (H_2, O_2, Cl_2 etc.) and the pair is shared equally between the nuclei of the atoms.



(a) Planetary model of a water molecule

(b) Three-dimensional model of a water molecule

(c) Structural formula for water molecule

Figure 2
Polar Covalent Bonds in a Water Molecule

- Atoms bonded with polar covalent bond have difference in the electronegativity and the one that has greater electronegativity attracts the shared pair more than the other, so the atom takes partial negative charge (δ^{+}), the other one takes on partial positive charge (δ^{-}).

For example: $H^{\delta+} – Cl^{\delta-}$ (HCl) $H^{\delta+} – O^{2\delta-} – H^{\delta+}$ (H_2O)

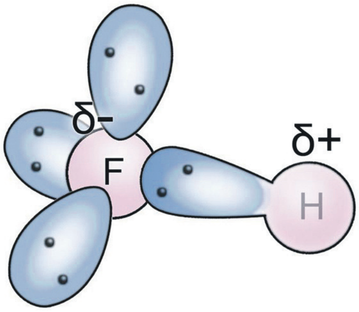
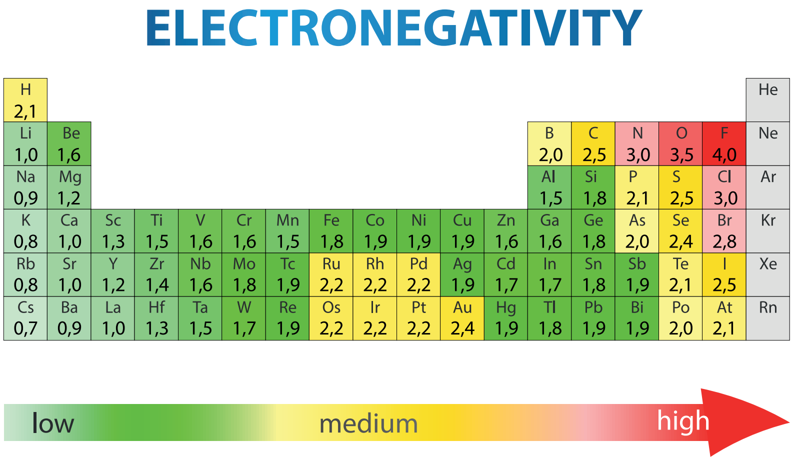


Figure 3
Polar bond in HF



H 2,1																	He
Li 1,0	Be 1,6											B 2,0	C 2,5	N 3,0	O 3,5	F 4,0	Ne
Na 0,9	Mg 1,2											Al 1,5	Si 1,8	P 2,1	S 2,5	Cl 3,0	Ar
K 0,8	Ca 1,0	Sc 1,3	Ti 1,5	V 1,6	Cr 1,6	Mn 1,5	Fe 1,8	Co 1,9	Ni 1,9	Cu 1,9	Zn 1,6	Ga 1,6	Ge 1,8	As 2,0	Se 2,4	Br 2,8	Kr
Rb 0,8	Sr 1,0	Y 1,2	Zr 1,4	Nb 1,6	Mo 1,8	Tc 1,9	Ru 2,2	Rh 2,2	Pd 2,2	Ag 1,9	Cd 1,7	In 1,7	Sn 1,8	Sb 1,9	Te 2,1	I 2,5	Xe
Cs 0,7	Ba 0,9	La 1,0	Hf 1,3	Ta 1,5	W 1,7	Re 1,9	Os 2,2	Ir 2,2	Pt 2,2	Au 2,4	Hg 1,9	Tl 1,8	Pb 1,9	Bi 1,9	Po 2,0	At 2,1	Rn

Figure 1

Some molecules with polar bonds also possess a dipole. Dipoles are molecules with positive and negative end. Some other molecules could have polar bond but to be non-polar because of the molecules' geometry.
According to the number of bonding electron pairs there are three types of covalent bond: single for one shared pair, double for two shared pairs, triple for three shared pairs. We denote these types of bonds with dash for each pair. (H – H, O = O, N≡N).

4.2. Ionic and metallic bonding

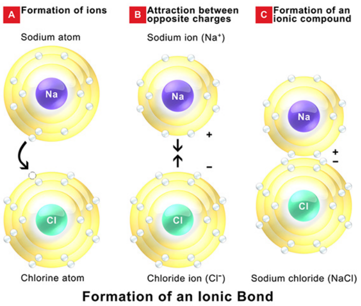


Figure 4
Polar bond in HF

As we said in the previous lesson, there are atoms that tend to lose electrons (metals) and others that tend to gain electrons (nonmetals). When two of this type of atoms react, one or more electrons are completely transferred and ions are produced. The bond between metal and nonmetal in most cases is called an ionic bond. There are exceptions. This bond involves strong electrostatic attraction between two opposite charged ions and the elements have huge difference in the amount of electronegativity.
When an atom loses electron it turns into a positive ion, called cation. The ion has positive charge because the positive charges in the nucleus are more than the negative in the electron shell (Na^{+} has $11p^{+}$ and $10e^{-}$).

$$Na - e^- \rightarrow Na^+ \ (\textit{sodium cation})$$

When an atom gains an electron it turns into negative ion, called anion. The ion has negative charge because the negative charges in the shell are more than the positive in the nucleus. (Cl^- has $17p^+$ and $18e^-$)

$$Cl + e^- \rightarrow Cl^- \ (\textit{chlorine anion})$$

Key terms

- covalent bond
- unshared pair
- shared pairs
- polar covalent bond
- single bond
- double bond
- triple bond
- electronegativity
- dipole
- ionic bond
- ionic compounds
- cation
- anion

The ionic compounds are represented with empirical formulas. Chemical equations are used to represent the formation of an ionic bond. In them, the transition of electrons is denoted by arrows from the one which loses electrons to the one which gains the electrons and the charge in the compound is written as superscript. The charge of an ion is equal to the valency of the element.

$$\overset{2.1e^-}{\overbrace{2Na + Cl_2}} \rightarrow 2Na^+Cl^-$$

$$\overset{2e^-}{\overbrace{Ca + Cl_2}} \rightarrow Ca^{2+}Cl_2^-$$

When the difference in electronegativity (χ) of the atoms is less than 1,67 the bond is covalent polar.

When the difference in electronegativity (χ) of the atoms is greater than 1,67 the bond is ionic.

Metals have a crystal structure. As metals, they easily lose electrons and transfer into cations. All the valence electrons are in a constant motion and this way they form sea of electrons. A metallic bond is electrostatic attraction between metal cations and delocalized electrons.

Solve the problems below

Problem 1. A student wrote in his notebook the following information. I have two compounds. One of them is an essential nutrient and is used in healthcare like 0,9 % solution to help preventing dehydration. It is used also as a food preservative and as a seasoning with a salty taste. It is also used to de-ice roads and sidewalks. I put it into the flame of a spirit lamp and the color of the flame becomes yellow. That means it contains an element with atomic number 11.

The other compound is a colorless gas which is a product of a reaction between chlorine and hydrogen. When I add water, the gas dissolves. I tested it with universal indicator and it turned red.

a) Which are the compounds: write their names and chemical formulas?

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b) Write the chemical equations for the reactions, using simple substances for resulting them.

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c) What is the type of bonding between the atoms in these compounds?

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d) Use diagrams and equations to show the bond between the substances.

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Problem 2. Read the text below and find the mistakes.

Atoms bind and form bonds because in bounded state atoms have higher energy. Bonding between nonmetals which share a single pair of electrons is called covalent. When there is no difference between the electronegativity of the atoms the bond is polar. The difference refers to a nonpolar bond. The bond in HBr is covalent nonpolar, while in CaO – it is ionic. When metal and nonmetal bind, ionic bond is formed. The atoms that participate in ionic bond form ions. The charge of each ion depends on the valence. For example, aluminum loses 3 e^- and its charge is 3^+. Another type of bond is metallic bond._It is formed due to an electrostatic attraction between the metal cations and the electrons which are delocalized.

Problem 3. Write down the mechanism of the bond formation in the following substances a) H_2S b) Na_2S c) HF d) NH_3 e) Br_2 f) KI g) $CaCl_2$ h) O_2

Follow the examples:

a) $\cdot\mathbf{H} + :\overset{..}{S}: + \cdot\mathbf{H} \rightarrow H \; :\overset{..}{\underset{..}{S}}: \; H$ H – S – H   Covalent, single, polar bond

b) $\overset{2.1e^-}{2Na + S} \rightarrow Na^+_2S^{2-}$ Ionic bond

c) ……………………………………………………………………

d) ……………………………………………………………………

e) ……………………………………………………………………

f) ……………………………………………………………………

g) ……………………………………………………………………

h) ……………………………………………………………………

Problem 4. Connect the atoms in the boxes which can form covalent polar bonds (with a single line) and ionic bonds (with dotted line). Write down the molecular and empirical formulas of the resulting compounds.

Potassium	Chlorine	Oxygen	Hydrogen
Nitrogen	Sulfur	Calcium	Iodine

Covalent polar bonds

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Ionic bonds

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Problem 5. The ion of an unknown element E_1^- has 10 electrons and another unknown element has ion E_2^+ with 18 electrons.

a) How many protons do they have? Find them in the Periodic table and write their symbols and names.

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b) Write down the equation for the reaction between them.

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c) What type of bond is formed in the product?

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Crystals

5

The physical properties of matter determine a major part of its characteristics. Namely, those that can be measured without changing the composition of the substance. Physical properties include color, hardness, malleability, solubility, density, electrical conductivity, melting point, and boiling point. The physical properties of matter are related to both the type of chemical bond, and the way the particles are arranged in three-dimensional space. In crystalline solids or crystals, the particles are arranged in three-dimensional crystal lattice. Each crystal lattice is characterized by a unit cell, that is the smallest and the simplest repeating unit in the crystal, for example the simple cubic unit cell in Figure 1. There are four types of solid structure – molecular, atomic, ionic and metallic.

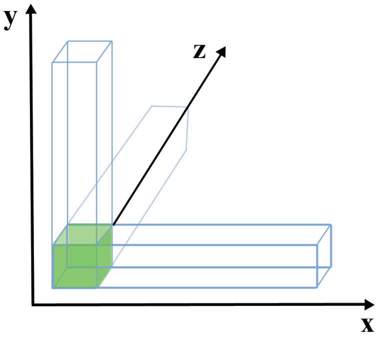

Figure 1

1. Molecular

- ➢ Particles are molecules
- ➢ Bonded by intermolecular forces (vanderwaals forces)
- ➢ Soft substances
- ➢ Low melting/boiling point because of weak molecular forces
- ➢ Poor electrical conductivity because there is no ions or electrons
- ➢ Solubility in water – diverse
- ➢ I_2, dry ice, sugar etc.

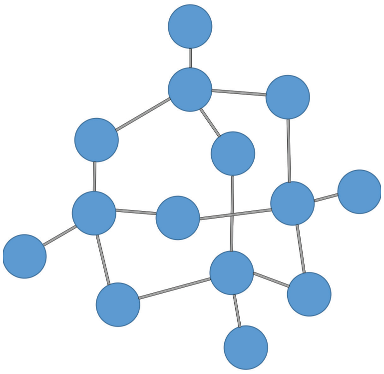

Figure 2
Diamond atomic lattice

2. Atomic

- ➢ Particles are atoms
- ➢ Strong covalent bond
- ➢ Very hard substances
- ➢ High melting/boiling point because of strong covalent bond
- ➢ Poor electrical conductivity because there is no ions or electrons
- ➢ Insoluble in water
- ➢ Al_2O_3, diamond, Si etc.

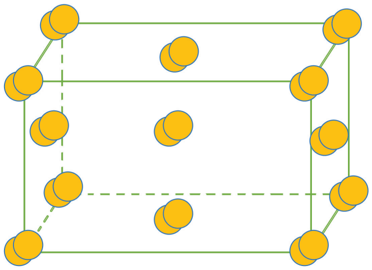

Figure 3
Iodine molecular lattice

3. Ionic

- ➢ Particles are ions with opposite charge
- ➢ Ionic bond
- ➢ Hard substances but brittle
- ➢ High melting/boiling point because of strong electrostatic attraction
- ➢ Electrical conductivity is poor when they are solid and good when molten or aqueous

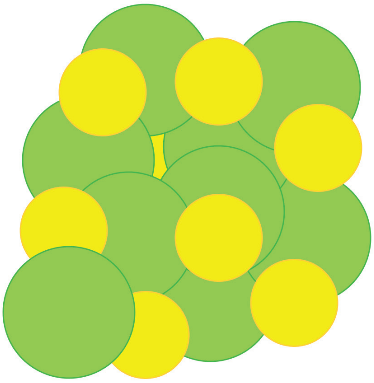

Figure 4
Sodium chlorine
ionic lattice

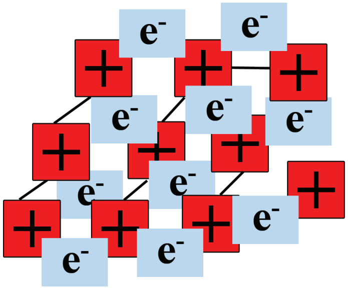

Figure 5
Metallic lattice

- Solubility in water – diverse
- NaCl, $CaCl_2$ etc.

4. Metallic

- Particles are positive ions and delocalized electrons
- Metallic bond
- Hard substances but malleable
- High melting/boiling point because of strong electrostatic attraction between positive ions and electrons
- Electrical conductivity is good because of mobile electrons
- Insoluble
- Metals and alloys

Solve the problems below

Problem 1. The substance **A** is known to have high solubility in water, both high melting and boiling points and to be very hard. Knowing these physical properties of the substance, determine the lattice type of **A**. Provide a list of four substances (chemical formulas and names) that according to you might be good candidates for the substance **A**.

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Home project work Growing crystals

Add a tablespoon of salt and sugar in two different cups and dissolve them in water. Filter the solutions through cotton and leave them in shallow containers in a warm place for several days. Do not stir or shake them. Examine the resulting crystals with a magnifying glass.
1. Do you find a difference in the way the crystals look like?
2. What is the chemical bond between the particles in these compounds?
3. Why do you think these differences occur?

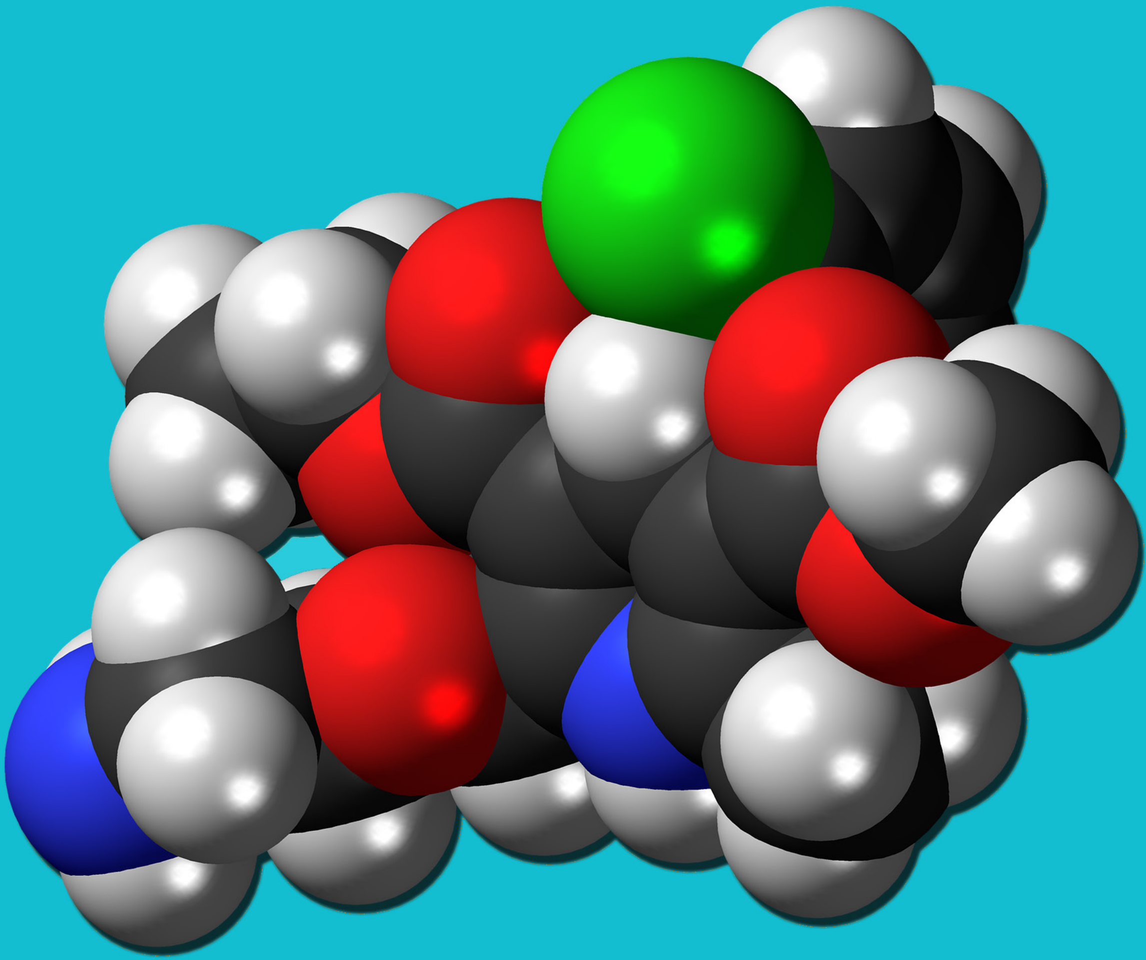
Key terms

- unit cell
- crystal solid
- molecule crystal lattice
- ionic crystal lattice
- atomic crystal lattice
- metallic crystal lattice
- brittle
- electrical conductivity
- solubility
- malleable
- melting/boiling point

INORGANIC CHEMISTRY

Part II

Metals and their compounds



Chemical elements of IIA group. Magnesium and Calcium and their compounds

6

General characteristic of the elements. Magnesium and Calcium

Alkaline earth metals beryllium, magnesium, calcium, strontium and barium, constitute II A group of the periodic table. They have two valence electrons in the outermost shell and losing them become positively charged ions M^{2+}. As the atomic number increases, the radius increases, the metallic properties increase as well. (Figure1) The earth metals are all solids; with silvery-white color (Be is silvery – grey). They have high electrical and thermal conductivities. The presence of the elements of IIA group and their compounds can be identified through flame tests. Their metal ions give characteristic flame colors (Table 1).

Ion	Color
Mg	Intense white flame
Ca	Brick red
Sr	Scarlet
Ba	Apple green

Table 1

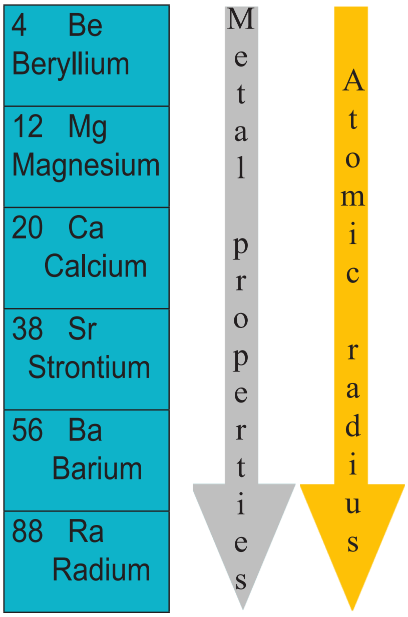
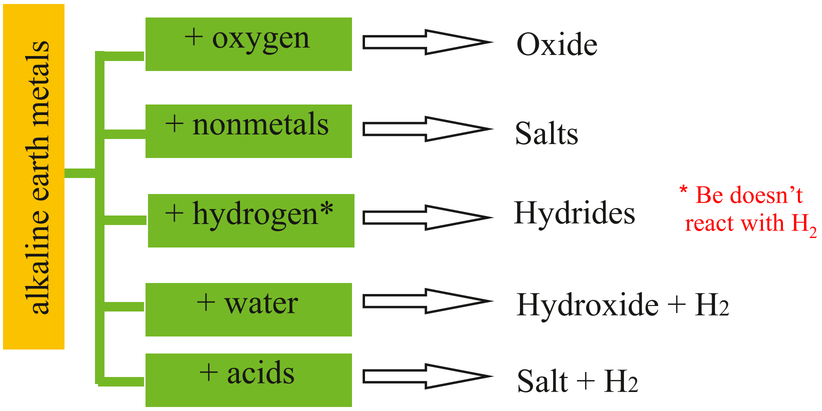


Figure 1

The elements of Group IIA (2) are highly reactive but less reactive compared to the Group IA elements All of them react with oxygen and nonmetals, water and acids as well. Three of the metals calcium, strontium and barium are stored in oil because of their high reactivity with oxygen and water vapor in the air. The most important chemical reactions for these metals are given on the graphic.



6

Chemical elements of IIA group. Magnesium and Calcium and their compounds

Because of their high reactivity the Group IIA (2) elements can't be found in free state in nature. Nevertheless, they form many compounds of great importance for our everyday lives. In Figure 2 you can see some of the most important uses of magnesium and calcium summarized.

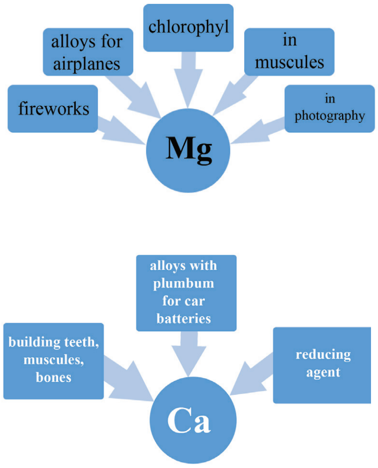


Figure 2

Calcium and magnesium compounds

Make a suggestion about the chemical properties of the compounds and the main chemical formulas of the oxides and hydroxides.

Calcium (II) oxide (CaO) is known as quicklime. It's a white crystal solid with ionic structure. The chemical properties are similar to the properties of already studied oxides of the alkali metals. On the graphic are shown all possible chemical reactions for calcium oxide.

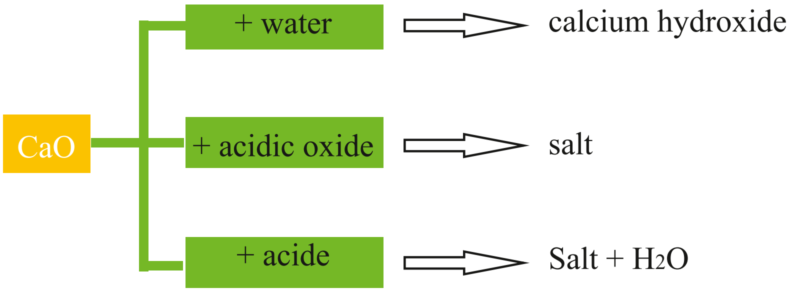


Figure 3
Calcium oxide powder

Calcium (II) hydroxide ($Ca(OH)_2$) is known as slaked lime. It's white, solid, ionic compound. It doesn't dissolve well in water and the heterogeneous mixture of slaked lime and water is called "lime milk". The chemical properties are shown on the graphic.

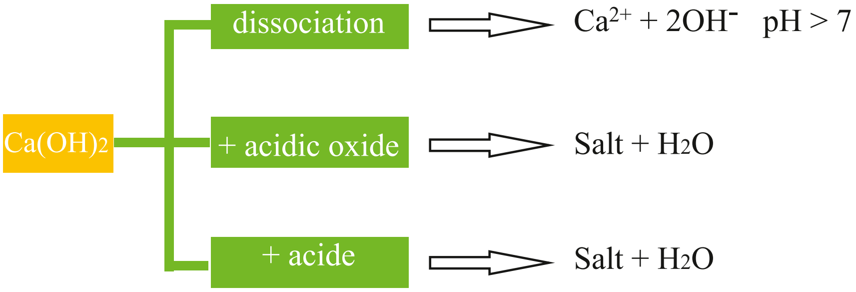


Figure 4
Rainbow color chalks

The calcium compounds are widely used in many fields. Quicklime is used for steel production while slaked lime is used in construction, disinfection, leather treatment and sugar production. Gypsum is among the most common building materials. Marble, limestone, chalk are composed of calcium carbonate. The shell of snails, corals and the shell of different cancroid contains calcium carbonate. Mixture of slaked lime, sand and water is a building material called mortar and mixture of slaked lime, blue vitriol ($CuSO_4$) and water is used for plant protection. The Epsom salt (magnesium sulfate heptahydrate, $MgSO_4 \cdot 7H_2O$), milk of magnesia (magnesium hydroxide, $Mg(OH)_2$), and citrate of magnesia are used in medicine as purgatives and antacids.

Solve the problems below

Problem 1. Hard water vs Soft water

Have you ever noticed when you wash your hands, there are white spots on the sink which are difficult to be cleaned? Or maybe sometimes it feels like you can wash away the soap from your hands. Probably the reason for both is the hardness of the water. There is temporary and permanent hardness of the water which are caused by calcium and magnesium compounds. Found on the internet or library information for

a) softening water processes. Which are the compounds that cause permanent and temporary hardness? Write the chemical equations for the processes of softening the water.
b) Is there a chance water's hardness to harm our health? How?

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Problem 2. Draw a scheme of all possible reactions for magnesium, magnesium oxide and magnesium hydroxide and write down all the equations. What type of bonds do you think Mg MgO, $Mg(OH)_2$ have?

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Key terms

- reactive
- basic oxide
- basic hydroxide
- quicklime
- slaked lime
- Epsom salt
- ionic structure

Figure 5
Marble

Figure 6
Sea shell

6 Chemical elements of IIA group. Magnesium and Calcium and their compounds

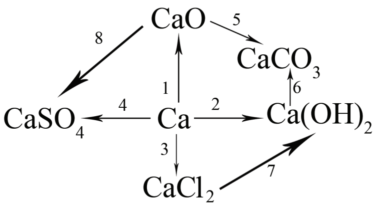

Figure 7

Problem 3. Write down all chemical equations (1 – 8) for the reactions given in the figure 7. Give the systematic names for the products.

1. ....
2. ....
3. ....
4. ....
5. ....
6. ....
7. ....
8. ....

Figure 8
Gypsum

Figure 9
Calcite CaCO$_3$

Home project "Shell less egg"

Tools and materials: a jar, a bottle of vinegar (it would be better if it's colorless), food coloring and an egg.

Instructions: Fill the jar with vinegar and gently put the egg inside. You can add few drops of your favorite food color. Make sure the vinegar covers the egg entirely. First changes should appear after about 12 hours. After 24 hours, checkup the progress and if needed drain some of the vinegar and add more. The entire experiment takes around two days. When the time has passed, take the egg out of the jar and put it in a cup filled with water. Rinse the liquid carefully. Do you see a naked egg?

Observations:

1. Which is the compound that composes the egg shell?
2. Vinegar contains an organic acid called acetic acid CH_3COOH. Ask your teacher to help you write the equation for the process.

Chemical elements of Group IIIA (13). Aluminum and its compounds

7

General characteristic of the elements

Group III-A includes boron (B) which is a non-metal and aluminum (Al), gallium (Ga), indium (In) – transition metals, thallium (Tl) – a metal. The elements in this group are commonly known as the Earth metals because their oxides constitute a major part of the Earth's crust. They have three electrons in the outermost shell and therefore they exhibit valency of 3 (except Tl). These elements form positive ions by losing 3 electrons $M - 3e^- \longrightarrow M^{3+}$. The atomic radius and the metallic properties increase with increasing atomic number in the group (like we have already seen in Group II (2) A (Figure 1).

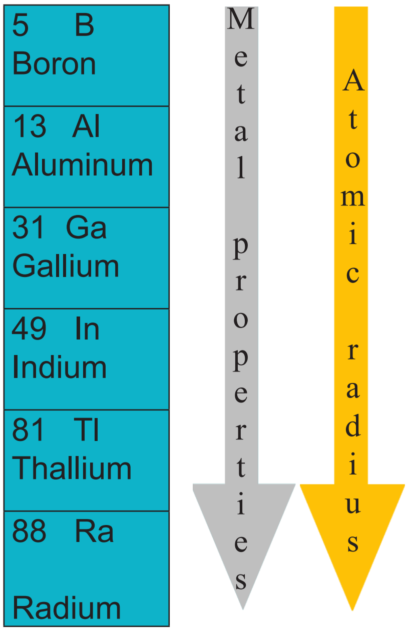

Figure 1

Aluminum

In the Earth's crust, aluminum is the most abundant metallic element (8.23% by mass) and the third most abundant of all elements (after oxygen and silicon)

Aluminum, Al, is the most abundant metal in the Earth's crust and the third most abundant element on Earth after Oxygen and Silicon. It is a light metal with silvery-white color, an excellent thermal and electrical conductor. If we add concentrated acid, the metal's surface covers with a layer of aluminum oxide and that process is called passivation. Aluminum is used as a reducing agent as well. The reaction is called aluminothermy. This reaction produces high temperature (exothermic, +Q) and in it aluminum takes away oxygen from another highly melting metal. This process is used for producing iron from its oxide (Fe_2O_3).

Figure 2
Aluminothermy

$$Fe_2O_3 + 2\,Al \longrightarrow Al_2O_3 + 2\,Fe$$

Aluminum reacts with alkalis and dilute acids forming salts.

$$2\,Al + 2\,NaOH + 2\,H_2O \longrightarrow 2\,NaAlO_2 + 3\,H_2$$

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

On the diagram you can see its chemical properties

7 Chemical elements of Group IIIA (13). Aluminum and its compounds

Figure 3 Ruby

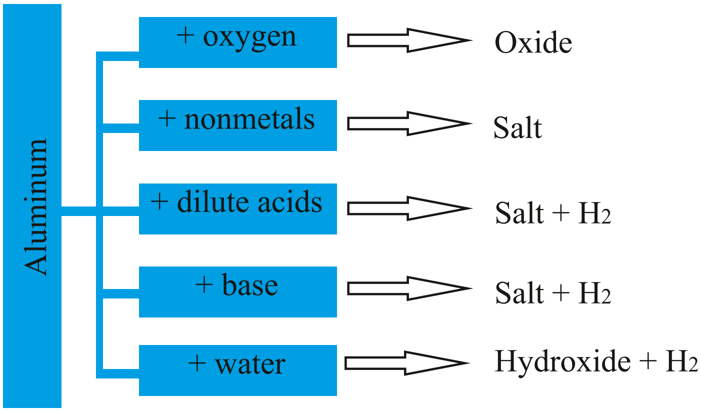

Figure 4 Sapphire

Aluminum compounds

In nature aluminum (III) oxide (Al_2O_3) occurs as the mineral corundum. The gemstones ruby (red color) and sapphire (blue color) are two varieties of corundum (Fugure 3 and Figure 4). Corundum is insoluble in water, acids and bases. Aluminum (III) oxide is amphoteric and reacts with both acids and bases.

Aluminum (III) hydroxide $Al(OH)_3$ is mostly found in nature as the mineral gibbsite. It appears as a white powder and has low solubility in water. Like aluminum (III) oxide, aluminum (III) hydroxide is amphoteric. By dehydration of $Al(OH)_3$, Al_2O_3 can be produced. The product of the reaction of a water solution of aluminum salt with alkali base, is aluminum hydroxide.

$$AlCl_3 + 3\ NaOH \longrightarrow Al(OH)_3 + 3\ NaCl$$

The chemical properties of aluminum (III) oxide aluminum (III) hydroxide are given in Figure xx.

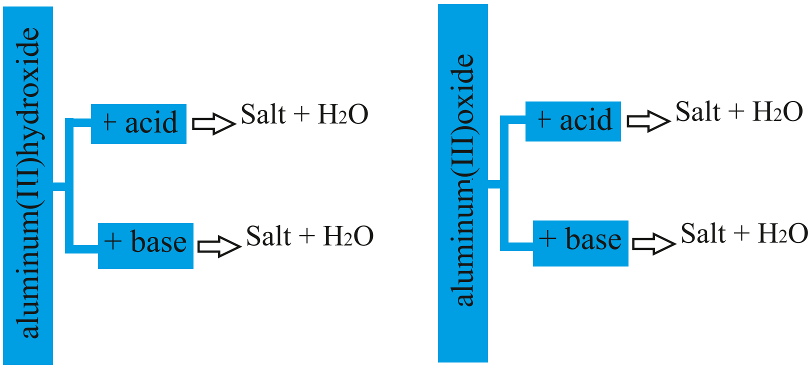

Figure 5

Key terms

- amphoteric oxide
- amphoteric hydroxide
- passivation
- aluminothermy
- corundum
- ruby
- sapphire

Chemical elements of Group IIIA (13). Aluminum and its compounds

7

Airplane

Aluminium takeout tray

Cans

Aluminium foil closeup

Figure 6 Uses of aluminium

Solve the problems below

Problem 1

Aluminum is a widely used metal in our everyday life. Select the correct applications for aluminum by putting = in the circles. Connect the selected application to a certain physical property by writing it down below.

○ Aircraft construction

....

○ Household

....

○ Batteries

....

○ Car parts

....

○ Producing metals

....

○ Vulcanization

....

○ Part of the mortar ○ Wires

....

○ Foil

....

Problem 2. A salt of aluminum in combination with slake lame is used to purify water. The salt is the product of the reaction between aluminum hydroxide and sulfuric acid. Write the equation of this reaction and the name of the salt.

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Problem 3. Think of three different ways to obtain aluminum (III) oxide. Write the equations of the reactions. Is it possible to synthesize $Al(OH)_3$ from Al_2O_3?

1. ....
2. ....
3. ....

Problem 4. Chromium is used to harden steel, for bathroom fittings and for platting mirrors. It can be produced from its oxide and aluminum and during the process a great amount of heat is released. Write the equation and name the reaction.

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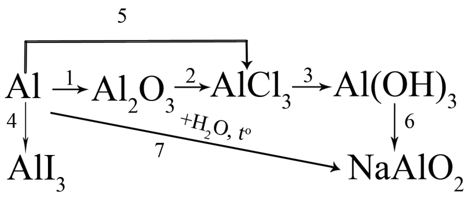
Problem 5. Write all the chemical equations for the reactions on the diagram and name the products.



1. ....
2. ....
3. ....
4. ....
5. ....
6. ....
7. ....

Metals and their compounds in our daily life

8

Nearly 24% of the planet's mass is made up of metals and about two-thirds of all elements are metals. According to the Royal Society of Chemistry, there are 94 metals listed in the Periodic Table. Iron and aluminium are two of the four most abundant metals.

Metals are everywhere and metal alloys are constantly manufactured to satisfy our demands. Copper can be found in the electric toothbrush and alarm clock, while aluminium-coated iron wire resistors are extremely likely to be found in the coffee maker, and the kitchen sink is frequently made of stainless steel. Because metal foil has no taste or smell, it is commonly used in food wrapping. Aluminium shelves and copper wire are found in the freezer's compressor. Metals have been used for a very long time and we know a lot about their optimal usage in materials.

The human body is primarily made up of hydrogen, oxygen, carbon, and nitrogen. It also contains elements like zinc, iron, calcium, magnesium and copper. All biological life and all living things depend on these substances, despite the fact that their amounts are quite small.

Magnesium is essential for the development of the bones, the health of the nerves and muscles, and the normal cell function. Calcium is essential for the health of the bones, teeth, and muscles as well as for the blood coagulation.

The consumption of metals has increased exponentially over the last 100 years. Scientists are aware that the vast majority of metal items which are available impact the environment. Yet, there is a circulation of metal from products into the environment at some point. It is crucial to understand whether this could have a negative impact on the environment or human health.

Metals – in Society
and in the Environment

Project

Project 1. Do research and find information about:

1. The daily recommended amounts of magnesium and calcium you need.

2. What happens with your body if you don't get enough magnesium and calcium?

3. A healthy diet is providing an adequate amount of calcium and magnesium to those who consume it. Make a menu that includes food rich in these elements providing the required daily amount.

8 Metals and their compounds in our daily life

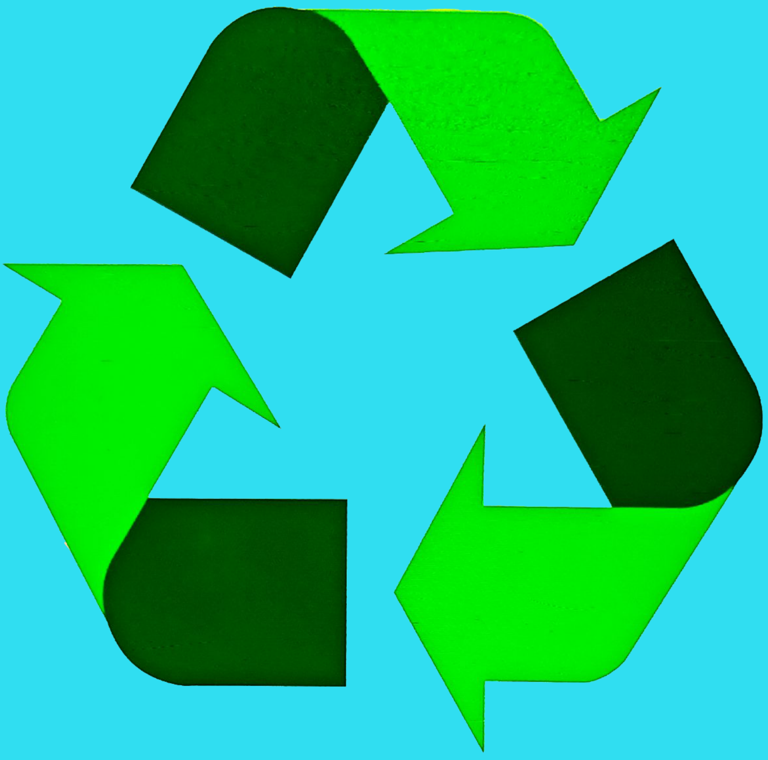
Project 2. Just smile

1. Do your research and find out which minerals and why are important for your teeth.
2. Read the medical article that tells everything you need to know about the type of toothpaste you need to have a beautiful smile and share a short summary with the class.

https://www.medicalnewstoday.com/articles/fluoride-toothpaste#is-it-safe

Part III

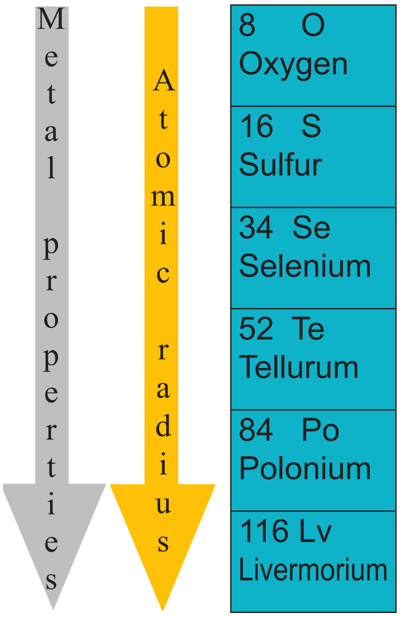
Nonmetals and their compounds



9

Chemical elements of Group VIA(16). Sulfur and its compounds

General characteristic of the elements



Group VIA(16) contains six elements oxygen (O), sulfur (S), selenium (Se), tellurium (Te) polonium (Po) and livermorium (Lv), often called the chalcogens. The atoms of these elements have six electrons in the outermost shell distributed in two electron pairs and two unpaired electrons. These atoms usually gain electrons and become negatively charged ions $E + 2e^- \longrightarrow E^{2-}$. They exhibit valency of 2 relative to hydrogen and 2 and 4 relative to oxygen. Group VIA(16) elements are classified as non-metals. Some of these elements exist in different forms in the same physical state. This property is called allotropy and the element's different forms – allotropes. For example, the element oxygen occurs in nature as two allotropes – O_2 (Oxygen) and O_3 (ozone). Sulfur occurs as many natural allotropes, more than any other element.

Sulfur

The element Sulfur (Figure 1) can be found in pure native form on Earth but usually occurs as minerals – pyrite (FeS_2), sphalerite (ZnS), galena (PbS) (Figures 2, 3 and 4) and more. Sulfur is non-metallic with molecular lattice. The sulfur atoms form cyclic octoatomic molecules S_8. The most stable sulfur allotropes are rhombic sulfur, monoclinic sulfur and amorphous sulfur. They have different properties due to the different arrangement of the atoms in the lattice. (Figure 5 allotropes of sulfur)

Figure 1

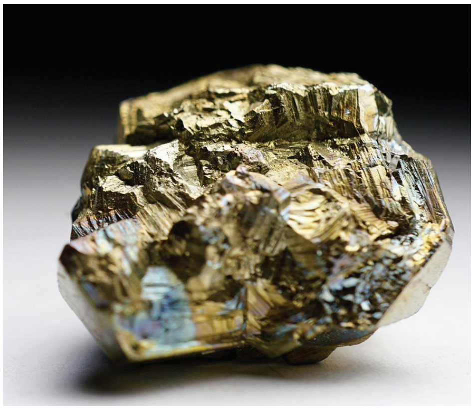
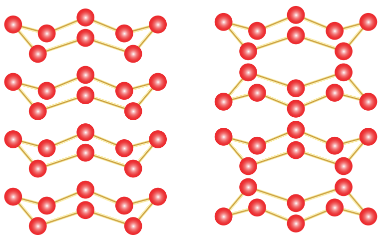


Figure 2
Pyrite

Figure 3
Sphalerite

Allotropes of Sulfur



Rhombic Sulfur

Monoclinic Sulfur

Figure 5

Figure 4 Galena

Chemical elements of Group VIA(16). Sulfur and its compounds

9

Problems

Problem 1. When hydrogen gas is passed over boiling sulfur a poisonous, rotten egg smelling gas is formed. The same gas is obtained when pyrite reacts with hydrochloric acid. If the gas is dissolved in water a weak acid is formed.

a) Write the chemical equations of these processes and name all products.

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b) What do you think? Is it possible the weak acid to react with a strong base? If yes, choose an alkali base and write the chemical equation for the process.

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c) What is the name of the reaction?

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Problem 2. Choose the right word and write the chemical equations of the described reactions.

Sulfur burns in an environment of pure oxygen with blue / colorless flame. A gas with an acidic/basic properties and a suffocating/ rotten egg odor is formed. Sulfur exhibits valency of 2/4 relative to hydrogen. The water solution of hydrogen sulfide has pH < 7/ pH > 7. As a typical non-metal sulfur reacts with metals like iron and forms salts called sulphides/ sulphates.

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Chemical elements of Group VIA(16). Sulfur and its compounds

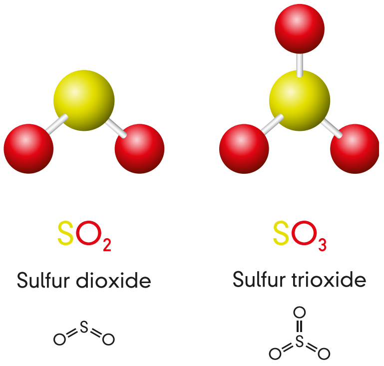

Figure 6

Sulfur compounds

Sulfur forms two oxides – SO_2 and SO_3 (Figure 6). They are both acidic oxides. SO_2 is a colorless gas with suffocating and sharp odor, heavier than the air and a pollutant causing acid rain. SO_3 is colorless viscous liquid which turns into gas at 44.8^0C. The chemical properties of the two oxides are given in Figure 7.

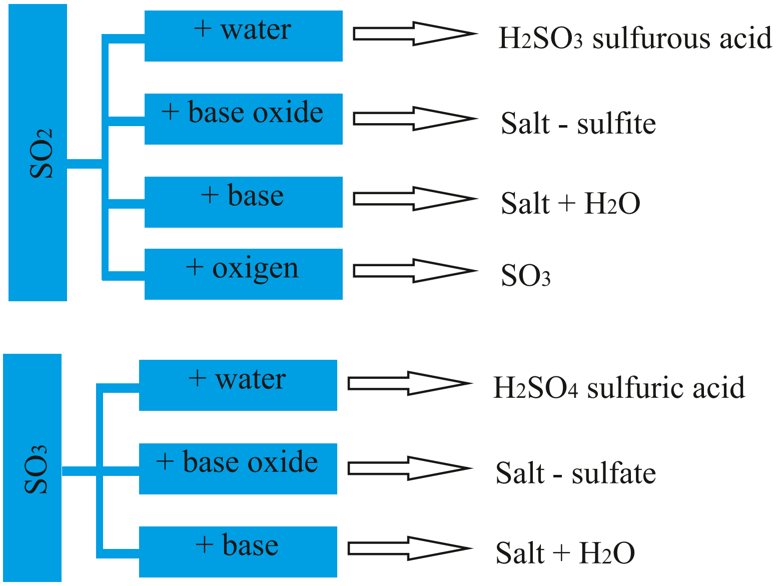

Figure 7

Problems

Problem 3. Which valency sulfur exhibits relative to oxygen in SO_2 and SO_3. Write down the equations for the reactions between:

SO_2 and sodium oxide;
SO_2 and calcium (II) oxide;
SO_3 and sodium hydroxide;
SO_3 and calcium (II) hydroxide.

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Sulfuric acid (Figure 8) is a colorless viscous liquid. It is soluble in water and a great amount of heat is released. It is hygroscopic and easily absorbs the water vapor from the air. 98% H_2SO_4 by mass is concentrated sulfuric acid. Sulfuric acid is a strong acid and a strong oxidizing agent. It has also powerful dehydrating properties. They are slightly expressed in the dilute form. Concentrated sulfuric acid has the power to remove (to extract) water from organic compound and to char them. (Figure 9)

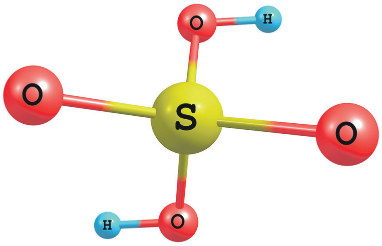

Figure 8

Figure 9
Reaction between concentrated H_2SO_4 and sugar

Concentrated sulfuric acid dissolves in water. Adding water to a concentrated acid may cause spattering of the acid. In order to avoid it you must add the acid slowly to water while stirring the solution as it's shown on in Figure 10.

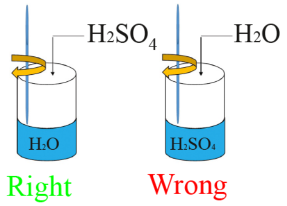

Figure 10

Problem 4. Read the text below and write the chemical equations for the reactions that describe the chemical properties of sulfuric acid.
Sulfuric acid dissociates into positive hydrogen H^+ ions and negative sulfate ions SO_4^{2-}, pH< 7. Concentrated sulfuric acid reacts with non-active metals such as Cu in two stages, basic oxides and bases. Metals, such as Fe, Cr and Al are passivized by it. Qualitative and quantitative test reaction for sulfate ion is Ba^{2+} because a white precipitate of barium sulfate is formed.

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Problem 5. Calcium sulfate, known as E516, is used for different purposes including food additive, stabilizer, firming and drying agent, building material etc. Which oxides must react with each other in order to be formed calcium sulfate. Write the chemical equation for the process.

Key terms

- rhombic sulfur
- monoclinic sulfur
- amorphous sulfur
- acidic oxides
- sulfur dioxide
- sulfur trioxide
- sulfurous acid
- sulfuric acid

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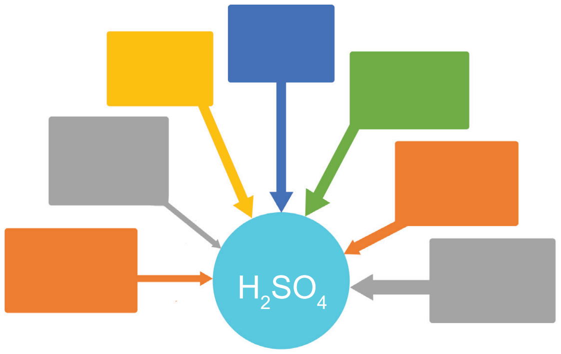
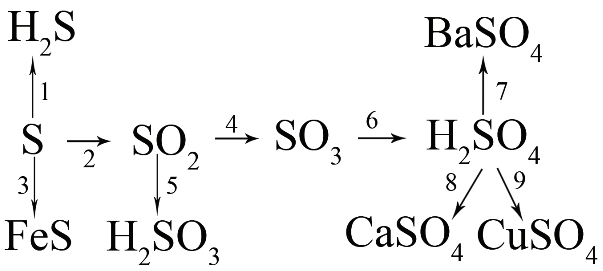
Problem 6. Read the text below and fill the diagram to define the uses of sulfuric acid.

The amount of sulfuric acid used in industry exceeds that of any other manufactured compound. The major uses of sulfuric acid are based largely on its strongly acidic character. It is used to produce ammonium sulfate and soluble phosphate fertilizers; to refine petroleum and to remove impurities from such products as gasoline and kerosene; to pickle steel; to produce dyes, drugs and disinfectants from coal tar; as an electrolyte itself or to produce metal sulfates for electrolytes; to manufacture other chemicals, such as hydrochloric and nitric acid; to produce textiles, paints, plastics, explosives and lead storage batteries. **(Holtzclaw, Robinson p. 672)**



Problem 7. Write the chemical equations of the reactions in the diagram and name the products.



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10

Chemical elements of Group VA (15). Nitrogen and its compounds

General characteristic of the elements

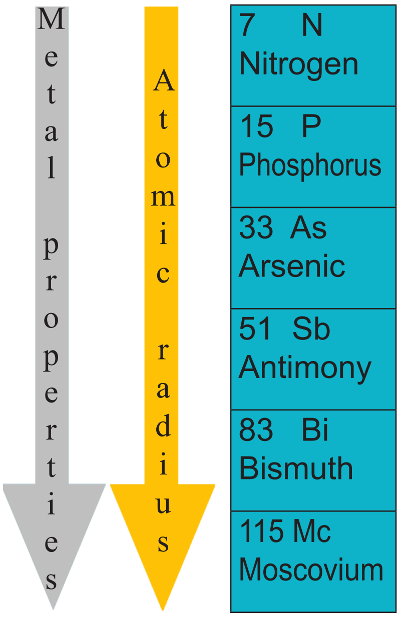

Figure 1

Group VA (15) contains six elements nitrogen (N), phosphorus (P) which are typical non-metals, arsenic (As), antimony (Sb), bismuth (Bi) which is a metal and moscovium (Mc). The atoms of these elements have five electrons in the outermost shell. They exhibit valency of 3 relative to hydrogen and variable valency relative to oxygen. With increasing of the atomic number in the group, their non-metal properties decrease and metal properties increase. Some of these elements have allotropes like phosphorus and arsenic. Phosphorus and arsenic have allotropes. The most common phosphorus allotropes are white and red phosphorus.

Nitrogen

The air we breathe is made up of approximately 78% nitrogen. Some of the most important biomolecules like DNA and proteins contain a significant amount of nitrogen. At the same time the name of this element comes from Greek and means “lifeless”.

Nitrogen (N_2) is a colorless and odorless gas with molecular lattice. Because the molecule is non-polar and the intermolecular forces are weak, the melting and boiling points of nitrogen are very low. The strong covalent triple bond in the nitrogen’s molecule makes it extremely unreactive. Extreme conditions are required in order to activate the molecule. ((Figure 2)

The needed energy for reaction between nitrogen and oxygen in the atmosphere is provided by lightning when thunder storms occurs). Nitrogen reacts with metals, oxygen and hydrogen at high temperature (except reaction with Li) forming nitrides, oxides and ammonia.

Figure 2

Problems

Problem 1. Using Lewis diagrams ~~to~~ draw the mechanism of formation of the bonds in nitrogen’s molecule. What is the type of the bonds? Is the nitrogen molecule polar or non-polar and why?

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Problem 2. Find on the internet

a) which is the natural source of nitrogen monoxide and what is the name of the method by which ammonia is synthesized from nitrogen and hydrogen? Under what conditions the reactions proceeds?

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b) Write the chemical equations for these processes.

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Nitrogen compounds

Problem 3. Nitrogen forms five oxides in which exhibits various valency relative to oxygen: 1 to 5. Fill in the table, writing their molecular formula, naming the oxides and using your textbook find some information about their physical properties. Two of them are neutral oxides while the others are acidic oxides. Which are neutral and why are they called like that?

Formula	Valence	Name	Physical properties
	I		
	II		
	III		
	IV		
	V		

Hint: $\overset{III}{N}_2\overset{II}{O}_3$ *LCM (3;2) = 6 - subscript for nitrogen 6:3=2, subscript for oxygen 6:2=3*

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Problem 4. Read the text below, answer the questions and write the equations.

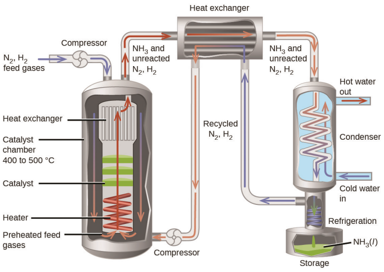

Figure 3
Industrial synthesis of ammonia

Ammonia is one of the most important nitrogen compounds. (Figure 3) Industrial synthesis of ammonia It is a suffocating and colorless gas with sharp odor, twice as lighter than the air. It's very well dissolved in water and reacts with it. The solution is called ammonia water. It dissociates into positive NH_4^+ (ammonium ion) and hydroxide ion (OH^-). Ammonia water can react with acids such as H_2SO_4, HCl, HNO_3 forming nitrates.

1. What is the bond type in the ammonia molecule? Write the Lewis dot formula of the molecule and draw the structural formula.

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2. Write the equation of the ammonia water dissociation. What is the pH value (>/</=7) of the solution and what are its chemical properties: acidic or basic? What is the color of phenolphthalein in ammonia water solution?

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3. Write the equations of the formation of ammonium sulfate, ammonium nitrate and ammonium chloride from ammonia water. What is the common name of the ammonium chloride? What is ammonium nitrate used for in practice?

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There are two nitrogen containing acids – nitric acid (HNO_3) and nitrous acid (HNO_2) both formed from the interactions of nitric oxides with water – NO_2, N_2O_5 for HNO_3 and N_2O_3 for HNO_2. Concentrated nitric acid is a 65% water solution, colorless which at 0^0C decomposes into nitrogen dioxide, water and atomic oxygen

$$2HNO_3 \longrightarrow 2\,NO_2 + H_2O + O$$

Figure 4

Nitric acid is a strong oxidizing agent (Figure 4) and can react with inactive metals. Same as sulfuric acid, the reaction between Cu and HNO_3 takes place in two steps. During the first step copper (II) oxide, nitric dioxide and water are produced. After that the metal oxide reacts with nitric acid and the products are salt and water.

1 step $Cu + 2\ HNO_3 \longrightarrow CuO + 2\ NO_2 + H_2O$

2 step $CuO + 2\ HNO_3 \longrightarrow Cu\ (NO_3)_2 + H_2O$

Summarized $Cu + 4\ HNO_3 \longrightarrow \underset{\text{copper (II) nitrate}}{Cu(NO_3)_2} + 2\ NO_2 + 2\ H_2O$

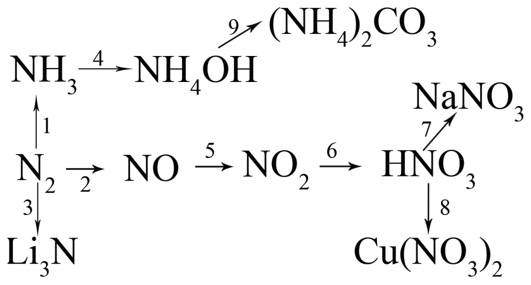
Some metals (Al, Cr, Fe) are passivated by concentrated nitric acid at room temperature. The diluted nitric acid reacts with ~~active~~ metals, basic oxides, bases and salts of weak acids.

$$4\ Zn + 10\ HNO_3 \longrightarrow 4\ \underset{\text{zinc (II) nitrate}}{Zn(NO_3)_2} + NH_4NO_3 + 3\ H_2O$$

$$MgO + 2\ HNO_3 \longrightarrow \underset{\text{magnesium (II) nitrate}}{Mg(NO_3)_2} + H_2O$$

$$Na_2CO_3 + 2\ HNO_3 \longrightarrow 2\ \underset{\text{sodium nitrate}}{NaNO_3} + H_2O + CO_2$$

Problem 5. Write the chemical equations of the reactions in the diagram and name the products.



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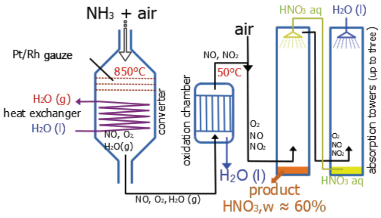

Figure 5

Problem 6. Ostwald's method (Figure 5) for producing nitric acid is very important for the chemical industry. Examine the figure and write down the chemical equations that describe the different stages of its obtaining.

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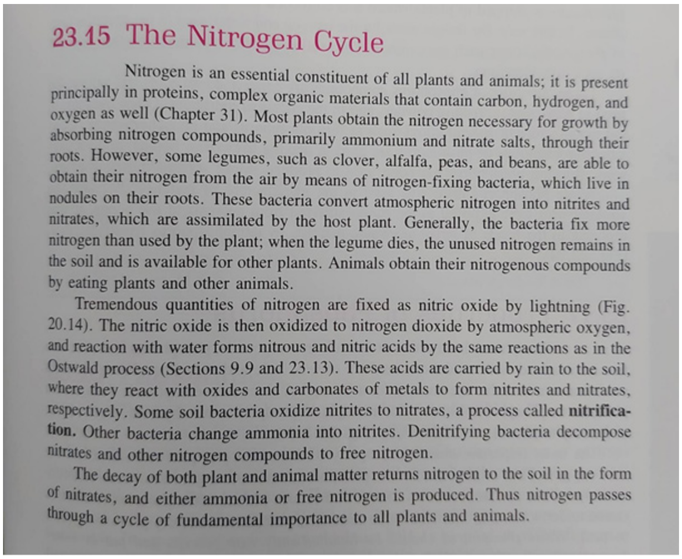
2. ……………………………………………………………………………
3. ……………………………………………………………………………

Problem 7. Nitrogen cycle

The text below is from the textbook General chemistry, Holtzclaw and Robinson, 1988 and it explains the nitrogen cycle. Read it carefully and fill in the figure that represents the cycle, using the words: lightening, nitrogen fixing bacteria, nitrification, denitrifying bacteria, nitrogen in plants, nitrogen in animals, plants' nutrition.



23.15 The Nitrogen Cycle

Nitrogen is an essential constituent of all plants and animals; it is present principally in proteins, complex organic materials that contain carbon, hydrogen, and oxygen as well (Chapter 31). Most plants obtain the nitrogen necessary for growth by absorbing nitrogen compounds, primarily ammonium and nitrate salts, through their roots. However, some legumes, such as clover, alfalfa, peas, and beans, are able to obtain their nitrogen from the air by means of nitrogen-fixing bacteria, which live in nodules on their roots. These bacteria convert atmospheric nitrogen into nitrites and nitrates, which are assimilated by the host plant. Generally, the bacteria fix more nitrogen than used by the plant; when the legume dies, the unused nitrogen remains in the soil and is available for other plants. Animals obtain their nitrogenous compounds by eating plants and other animals.

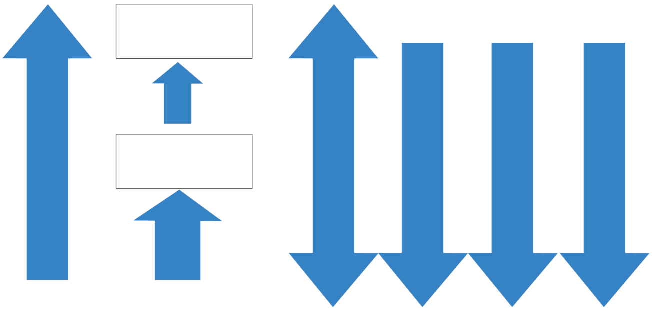
Tremendous quantities of nitrogen are fixed as nitric oxide by lightning (Fig. 20.14). The nitric oxide is then oxidized to nitrogen dioxide by atmospheric oxygen, and reaction with water forms nitrous and nitric acids by the same reactions as in the Ostwald process (Sections 9.9 and 23.13). These acids are carried by rain to the soil, where they react with oxides and carbonates of metals to form nitrites and nitrates, respectively. Some soil bacteria oxidize nitrites to nitrates, a process called **nitrification.** Other bacteria change ammonia into nitrites. Denitrifying bacteria decompose nitrates and other nitrogen compounds to free nitrogen.

The decay of both plant and animal matter returns nitrogen to the soil in the form of nitrates, and either ammonia or free nitrogen is produced. Thus nitrogen passes through a cycle of fundamental importance to all plants and animals.

Key terms

- Nitric oxides
- nitric acid
- nitrous acid
- oxidizing agent
- nitrates
- nitrites
- ammonia
- ammonium ion
- nitrogen cycle
- atmosphere fixation
- biological fixation
- industrial fixation

Nitrogen in the atmosphere



Chemical elements of Group IVA(14). Carbon and its compounds

11

General characteristic of the elements

Group IVA(14) contains the following elements: carbon (C), silicon (Si), germanium (Ge), tin (Sn), lead (Pb) and flerovium (Fl). Some of them are found in nature as minerals and gems like quartz and agate (SiO_2) (Figures 1 and 2)

Figure 1 Quartz

Figure 2 Agate

Problem 1. Using the periodic table
a) build up atom diagrams of the first three elements and write their Lewis' symbols.

b) what valency they exhibit with respect to hydrogen and oxygen.

c) In Figure 3 use arrows to show how the chemical properties and the atomic radius in the group change increasing the atomic number.
d) Compare the chemical properties of the elements in Group IVA(14), VA(15) and VIA(16). What is the reasoning behind your answer?

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6 C Carbon
14 Si Silicon
32 Ge Germanium
50 Sn Tin
82 Pb Lead
114 Fl Flerovium

Figure 3

The elements in Group IVA(14) are crystalline solids under normal conditions of temperature and pressure. Carbon, silicon and tin occur as allotropes in nature. All of them conduct electricity (except diamond).

Carbon

Carbon is found in nature as four allotropes – graphite, diamond, amorphous carbon and fullerene There is also one synthetic allotrope of carbon named graphene. Fullerene's molecule looks like a football ball because carbon atoms are bonded with single or double bonds forming closed net. Graphene has single layer of atoms forming honey comb lattice. (Figures 9, 10 and 11) Impure forms of carbon are charcoal and coke.

Figure 4 Carbon

Problem 2. Follow the links and use the resources to fill in the table
https://www.britannica.com/topic/diamond-gemstone
https://www.britannica.com/science/graphite-carbon

11 Chemical elements of Group IVA(14). Carbon and its compounds

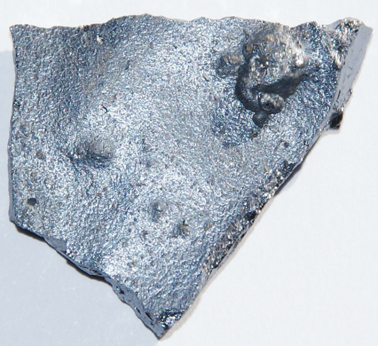


Figure 5 Silicon

Figure 6 Germanium

Figure 7 Tin

Figure 8 Lead

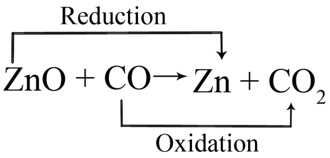
	Allotropes	
	Graphite	Diamond
Type of lattice		
Type of bond		
Physical properties		
Electrical conductivity		
Heat conductivity		
Usage		

Carbon has one electron pair and two unpaired electrons in the ground state.

The carbon atom moves easily to excited state by absorbing a certain amount of energy. The required energy is produced in the course of the chemical reactions. In the excited state, the carbon atom has four unpaired electrons. That is why carbon exhibits valency of 2 or 4.

Under normal conditions most forms of carbon are unreactive. Carbon reacts even with oxygen at very high temperature. The most common oxides of carbon are carbon monoxide (CO) and carbon dioxide (CO_2). When carbon reacts with oxygen at high temperature given sufficient amount of oxygen, carbon dioxide is produced. This process is known as complete combustion of carbon. When there is not enough oxygen present, carbon monoxide is produced. The process is called incomplete combustion. Carbon reacts also with hydrogen, and metals forming salts called carbides (CaC_2, Al_4C_3). Carbon doesn't reacts with water under normal conditions. When water steam is passed over charcoal at high temperature, a mixture of hydrogen and carbon monoxide, known as water gas (synthesis gas) is formed. The water gas is very important for the chemical industry. It is used to remove carbon dioxide from fuel cells, in Fischer – Tropsch process and for obtaining hydrogen for ammonia synthesis. Charcoal and coke are good reducing agents. Normally they are used to extract metals from their oxides.

Problem 3. Reduction is a process in which the amount of oxygen atoms in oxides decreases._Reducing agents bind the oxygen from other compounds. Oxidation is a process in which the amount of oxygen atoms increases. Oxidizing agents give oxygen to other compounds. These processes are always connected with each other as it is shown in the equation:



$$ZnO + CO \rightarrow Zn + CO_2$$

Complete the equations and use arrows to show which process is reduction and oxidation (like in the example) in them

1. $C + HgO \longrightarrow$

2. $Fe_2O_3 + C \longrightarrow$

3. $H_2 + O_2 \longrightarrow$

Problem 4. Mark the possible reactions in the table with ∨ and write the equations for carbon.

Substances	H_2	O_2	H_2O	Al
Nitrogen				
Sulfur				
Carbon				

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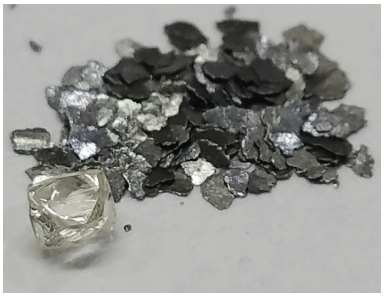


Figure 9
Diamond graphite

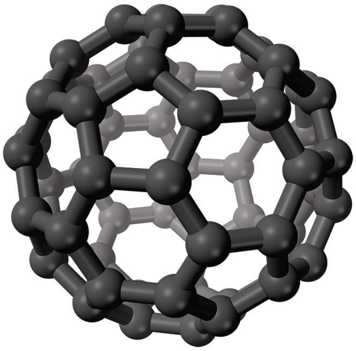


Figure 10
Fullerene

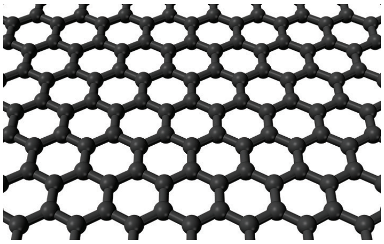


Figure 11
Graphene

Carbon compounds

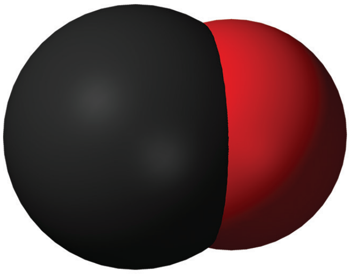


Figure 12
Carbon monoxide

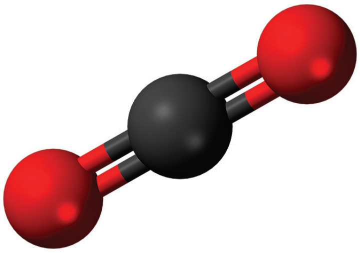


Figure 13
Carbon dioxide

Figure 14
Dry Ice

Problem 5. Read the text about carbon's oxides and fill in the table below.

Carbon's most prominent oxides are CO and CO_2. Figure 12 and Figure 13.. Carbon monoxide is a colorless, odorless, highly poisonous gas. Carbon monoxide poisoning can cause suffocating and even death. The reason is that the carbon monoxide molecule binds to a blood protein called hemoglobin. The main function of this protein is transport of oxygen to the cells. Normally oxygen binds to the hemoglobin molecule forming oxyhemoglobin. In the presence of high concentrations of carbon monoxide, another compound is formed: carboxyhemoglobin. This process prevents the blood from carrying oxygen. Carbon monoxide doesn't react with water. It's a neutral oxide. This oxide is a reducing agent. Carbon dioxide is colorless and odorless gas as well but not poisonous, contained in the atmosphere. It's heavier than the air, does not burn. At – 78,5^{0}C forms dry ice. (Figure 14). It reacts with water forming carbonic acid, basic oxide and bases forming salts. A test for carbon dioxide is reaction with lime water. When it's passed through a solution appears a white precipitation of $CaCO_{3.}$

	Carbon monoxide CO	**Carbon dioxide CO_2**
Physical state		
Color and odor		
Solubility in water		
Chemical properties		
Test reaction		

Carbonic acid H_2CO_3 has a molecule structure and covalent bonds. It has all the chemical properties specific for acids. When a solution is tested with litmus paper it turns light red because its acidic properties are weaker.

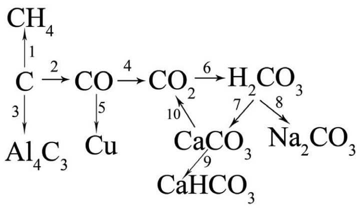
$$H_2CO_3 \longrightarrow 2\,H^+ + CO_3^{2-}$$

The salts of carbonic acid are called carbonates CO_3^{2-} and hydrogen carbonates HCO_3^-. All carbonates are white solids, most of them insoluble in water. They react with acids such as HCl which is a test reaction for them

$$CaCO_3 + HCl \longrightarrow CaCl_2 + H_2O + CO_2 \uparrow$$

H_2CO_3 is used for producing soda. It is found in the human body as well. It is formed in the blood. There it decomposes and exhales through the lungs.

Problem 6. Write the chemical equations for the reactions on the diagram and name the products.



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Problem 7. Find information on the internet or in the library about the carbon cycle. Write a short summary and draw a diagram of the cycle.

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12

Nonmetals and their compounds. Environmental protection

Figure 1
Greenhouse effect

Nonmetals are widely spread in nature despite their smaller count in the periodic table. Their compounds exist in all three physical states and they are soluble in water. As a result, they can migrate constantly across the natural world. Depending on their concentrations, they may have an impact on both individuals and the environment. After learning about the nitrogen and carbon cycles, you will have a better understanding of how the ecosystem will be affected by the excessive amounts of these nonmetal chemicals due to human activity.

Figure 2
Compressed
aluminium cans

1. Greenhouse effect

Before we claim the greenhouse gases are bad, first we need to understand that some greenhouse gases are necessary. The atmosphere would be 32.7 degrees Celsius colder without any. The majority of life on Earth would vanish. It's not about the gases but their concentration in the atmosphere.

The primary greenhouse gases are carbon dioxide, methane and nitrous oxide.

– **Carbon dioxide** is the most abundant gas in the atmosphere and the one responsible for the greenhouse effect. Despite the Covid-19 pandemic and the lockdowns, the concentrations of carbon dioxide reached their highest levels in 2020. Nature emits a huge amount of CO_2 but it is trapped by the plants in photosynthesis. The normal levels of CO_2 began to get higher over 10 000 years ago when people started to burn wood. In the middle of the 19th century, when we started using oil, kerosene, and gasoline for fuel, the pace increased. When they burn, the carbon joins the oxygen and becomes CO_2 which is released into the environment.

Figure 3
Recycling bottles

– **Methane** – 25 times more heat is trapped by CH_4, compared to CO_2. However, it vanishes after 10 to 12 years, while CO_2 has a 200-year existence. There are three main sources of methane – coal, natural gas, and oil transport and production account for 39% of the total amount. Another 27% comes from cow digestion.

Figure 4
Recycling bins

– **Nitrous oxide** accounts for 6 % of greenhouse emissions. Compared to the same amount of CO_2, it may absorb 300 times more heat. It is produced as a result of agricultural and industrial activities. It is also a byproduct of the combustion of fossil fuels and solid waste. The usage in fertilisers accounts for more than two-thirds of the total.

You can read more about air pollution coming from cars when you scan the QR code 1.

QR code 1

2. Acid rain

Acid rain is a major pollution issue that affects people all over the world. As the name shows, it indicates rain that is more acidic than normal. Natural sources of acid rain are volcanoes, lightning, dead plants and animal materials. But humans also contribute to acid rain. It is mostly produced by the combustion of fossil fuels. Sulphur dioxide and nitrous oxide present in the air are released when fossil fuels like coal, oil, and natural gas are burned to produce electricity. Nitric acid and sulfuric acid are produced when these chemical pollutants interact with the oxygen and water vapours in the air. That is how acid rain forms.

You can read more about what acid rain does to the environment when you scan the QR code 2.

QR code 2

Find information about how industry and we as individuals can prevent acid rain formation.

3. Waste

The earth's population is constantly growing, the consumption and the amount of waste increase as well. There is an endless list of all the waste humans throw every day.

Projects

Choose one of the projects and make a poster or a presentation.

1. Recycle, reduce and reuse

   – Pros and cons of recycling
   – Types of recycling items
   – Environmental protection

2. Green energy

   – What is green energy and are there different types of green energy?
   – Pros and cons of green energy
   – Which type of green energy do you think is best for environmental protection?

Figure 5
Water pollution due to domestic garbage

3. Pollution – Water and soil pollution

- Sources of water and soil pollution
- Environmental impacts
- How to prevent water and soil pollution

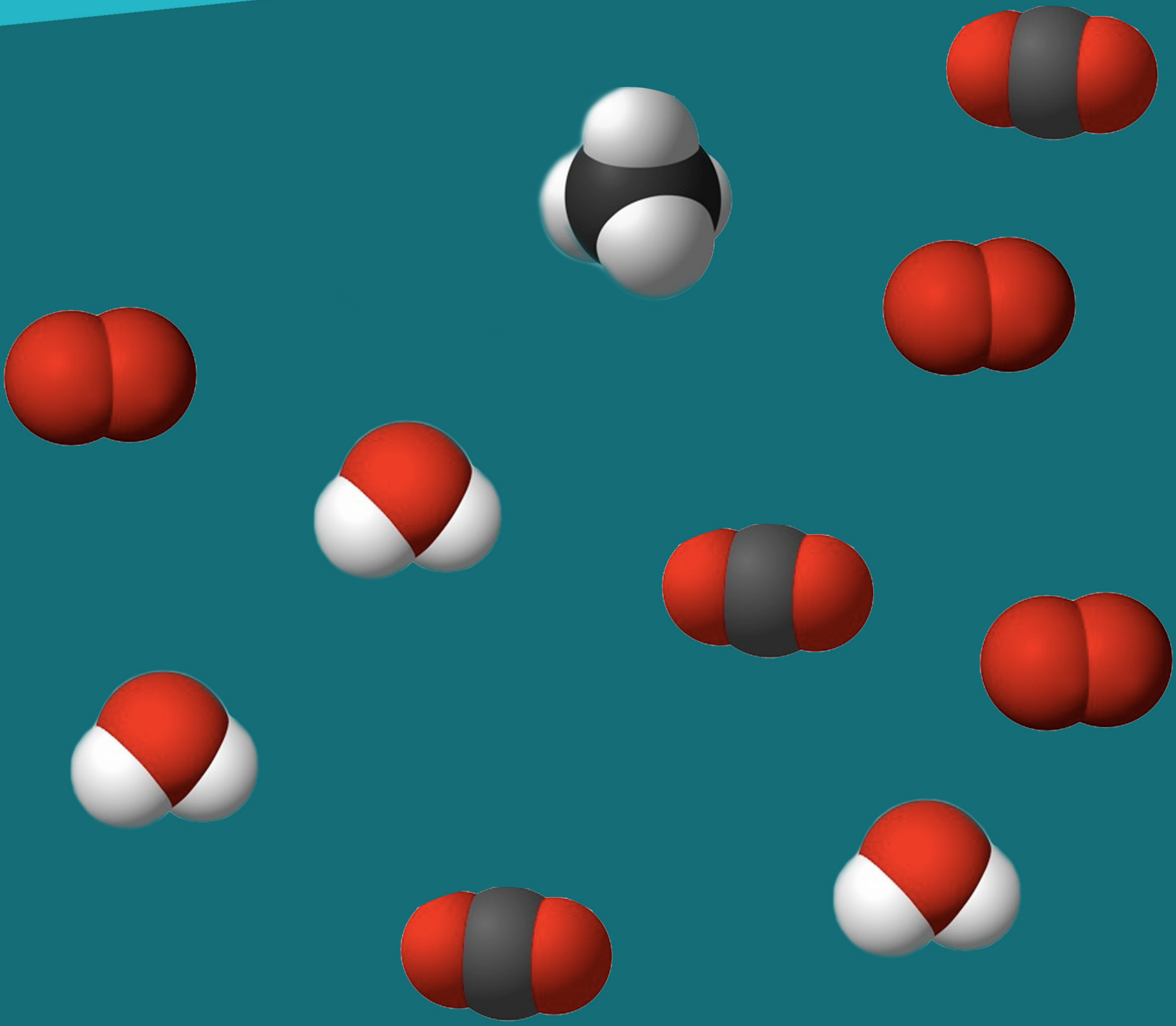
Figure 6
Damaged by acid rain

Figure 7
Waste disposal landfill

Renewable energy park

Figure 8
Logo Renewable Energy

Part IV
Stoichiometry



13

Molar mass, mass of a given substance and the mole

Have you ever been in a chemistry laboratory? Perhaps you have one at school? Was the first thing that grabbed your attention all the glassware full of different solutions or substances with different labels on them? Have you ever read what is written on these labels? What does it mean: 30% HNO_3, 10% HCl, HCl : HNO_3 1:1 or 15 % $CuSO_4$? Actually you can prepare all of these solutions and countless others on your own. You need to study a specific section in chemistry called stoichiometry. The word stoichiometry comes from Greek *stoicheion* "element" and *metron* "measure". In this chapter, we will consider some of the quantitative aspects of chemical formulas and reactions.

Mole definition

Figure 1
Amedeo Avogadro

The mole (n, mol) is a unit for amount of substance. The quantity amount of substance is simply the number of particles or elementary entities in a sample. Even a small amount of a substance contains an extremely large number of particles. For example, a drop of water contains over $1.5x10^{21}$ or 1.5 sextillion water molecules. Can you imagine how big is this number? In order to escape working with such big numbers, scientists have introduced the mole. One mole 1 mol of a substance contains $6{,}02\ x10^{23}$ entities. For example, 1 mol of H_2O contains $6{,}02\ x10^{23}$ water molecules, 1 mol of carbon contains $6{,}02\ x10^{23}$ carbon atoms. The number $6{,}02\ x10^{23}$ is called Avogadro's number, N_A (Figure 1). $N_A= N/n$, where N is the number of particles in the substance and n is the amount of substance in moles [mol].

Problem 1. Calculate the number of entities N in a) 2 mol NH_3 b) 2,5 mol H_2 c) 3 mol Al d) 4 mol sugar

Solution: a) $N_A = N/n$ $\ 6{,}02x10^{23} = N / 2$ » $N = 2.\ 6{,}02x10^{23} = 12{,}04x10^{23}$ molecules NH_3.

! The mole always refers and is written for specific entities. $n(O_2) = 1$ mol and n(O) = 1 mol have different meaning. Do you understand why?

Problem 2. Solve the problem following the example

a) Example: How many moles of hydrogen and sulfur atoms are there in 2 moles of hydrogen sulfide?
n(H) = 2.2mol = 4mol   n(S) = 1.2mol = 2mol

b) How many moles of hydrogen, carbon, and oxygen atoms are there in 4 moles of carbonic acid?

n(H) = n(C) = n(O) =

c) How many moles of hydrogen, carbon, and oxygen atoms are there in 3 moles of nitric acid?

n(H) = n(C) = n(O) =

d) How many moles of potassium and sulfide ions are there in 5 moles potassium sulfide?

$n(K^+)$ = $n(S^{2-})$ =

Molar mass and mass of a given substance

The molar mass is the mass in grams of one mole of the substance. The molar mass is defined as the mass of a chemical compound divided by the amount of substance of that compound (Figure 3). The molar mass is measured in kilograms per mole (kg/mol) or grams per mole (g/mol). In Figure 3 and table 1 you can find the relations between molar mass, mass of a substance and amount of substance and summary of mass terminology.

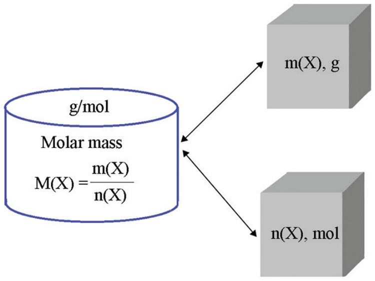


Figure 3

Mass	Definition	Units
Relative atomic mass A_r	The ratio of the average mass of one atom of an element to one twelfth of the mass of an atom of carbon-12.	
Relative molecular mass M_r	The ratio of the average mass of one molecule of an element or compound to one twelfth of the mass of an atom of carbon-12.	
Molar mass M	Mass of 1 mole of chemical entities	g/mol

Table 1

To calculate the molar mass of substance, you have to use the periodic table. Here's how the calculations are done:
1. The molar mass of a monoatomic element is equal to its atomic mass as given in the periodic table.

Example: $M(Ag) = A_r(Ag) = 108$ g/mol.

2. For molecules you must know their formula in order to calculate the molar mass.

Example: $M(O_2) = 2.\ A_r(O) = 2.\ 16 = 32$ g/mol

3. The value of the molar mass of a compound is equal to the molecular mass of that compound.

Example: $M_r\,(CO_2) = A_r(C) + 2A_r(O) = 12 + 2.16 = 12 + 32 = 44$, therefore $M(CO_2)$=44 g/mol.

Key terms

- the mole
- Avogadro’s number
- atomic mass
- molecular mass
- molar mass
- gram per mole

Problem 3. Sodium bicarbonate is a white solid commonly used as baking soda. It is one of the ingredients of baking powder. Calculate the molar mass of sodium bicarbonate. What is the amount of substance of sodium bicarbonate in a sample with mass 42 g?

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Problem 4. Calculate each of the following quantities:

a) Mass in grams of 0,5 mol slaked lame

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b) Number of moles of 20g ammonium carbonate

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c) Number of ammonia molecules in 51g ammonia

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d) Mass of $3,01x10^{23}$ sulfur dioxide molecules

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Problem 5. Zinc is an essential trace element, or a micronutrient, found in red meat, chicken, and fish. It's needed for the immune system to properly work. It is vital for the functionality of more than 300 enzymes in the human body. Copper is another essential trace element. Its deficiency could cause anemia-like symptoms, and sometimes osteoporosis. Perform the following calculations.

a) How many grams of Zn are in 1,5 mol of Zn?

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b) How many Cu atoms are in 127g of Cu?

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Molar volume

14

There is a certain relationship between volume and amount of substance known as molar volume (V_m). The molar volume is the volume of one mole of a substance at a specified pressure and temperature. The molar volume is defined as the volume of a chemical compound divided by the amount of substance of that compound. The SI unit for molar volume is cubic meter per mole (m^3/mol), but it's more practical to use dm^3/mol (L/mol) for gases and cm^3/mol for liquids and solids. In Figure 1 the relations between molar volume, volume and amount of substance are given. The units of volume are listed in Table 1, while the conversion factors between them are shown in Figure 2.

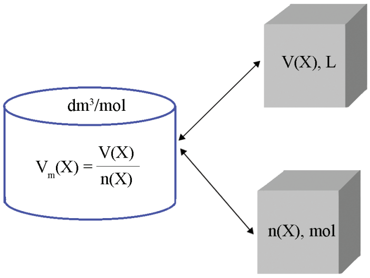

Figure 1

$$m^3 \xrightarrow{x\ 1000} dm^3 \xrightarrow{x\ 1000} cm^3$$

Figure 2

Units of volume	Name
1 m^3 (SI unit)	cubic meter
1 dm^3 = 1L	cubic decimeter or liter
1 cm^3 = 1mL	cubic centimeter or milliliter

Table 1

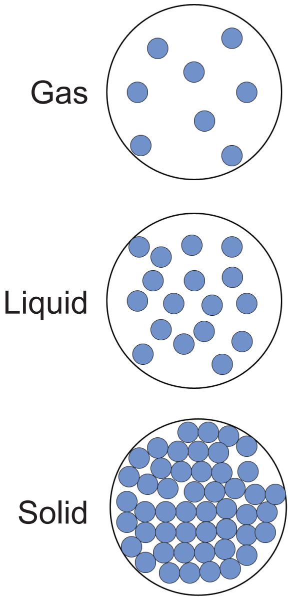

Figure 3 Physical state of substances

For solid or liquid substances, the molar volume has an exact value. The case with gases is different. Under the same conditions: temperature and pressure, an equal volume of different gases contains the same number of particles (equal moles) (Figure 4). One mole of any gas has the same volume – at a given temperature and pressure. This statement is known as Avogadro's law. It states that at temperature 0^0C (273^0 K) and pressure 1 atm (**S**tandard **T**emperature and **P**ressure, STP) every gas has molar volume equal to 22,4 L/mol.

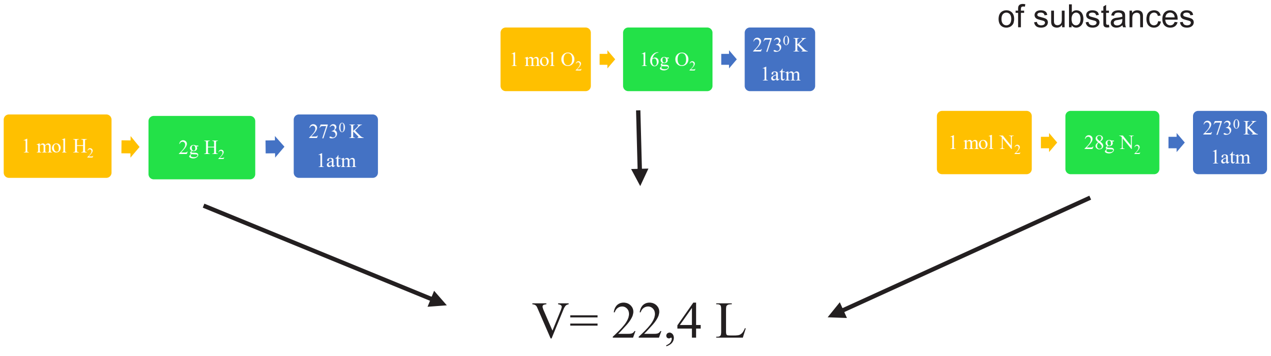

Figure 4
Avogadro's law

14

Molar volume

Problem 1. Convert the following to the indicated units

a) $2m^3$ = ……………….cm^3
b) ……………..dm^3 = 1000 cm^3
c) $1cm^3$/mol = ………….ml/mol
d) $24,08.10^{23}$ molecules SO_2
e) 80g SO_3
f) 46g NO_2

Problem 2. Calculate the volume measured at STP of the following gases. Which of them have equal volumes?

a) 0,5mol CO_2
b) 68g NH_3
c) 17g H_2S
d) …………. L/mol = $2dm^3$/mol
e) 2 L/mol = ……………ml/mol
f) $1m^3$/mol = ……….L/mol =…………. cm^3/mol

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Key terms

- Avogadro's law
- volume
- molar volume
- cubic decimeter per mole
- STP

f) ……………………………………………………………………………
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Problem 3. A sample of CH_4 (methane) has a volume of 246,4 L at STP. Calculate how many moles of the gas are present in the sample? What is the value of the mass in kg?

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Problem 4. Compare the mass of the gases a) butane (C_4H_{10}) b) chlorine c) nitrogen d) laughing gas e) oxygen with volume 14 dm^3 at STP.

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15 Mole (molar) ratios

In a chemical reaction, the atoms in one or more substances reorganize. Each reaction can be written with a chemical equation which contains reactants (on the left side of the arrow) and products (on the right side of the arrow). The chemical equation actually contains very important information about the chemical identity of the participants in the reaction and about their relative quantities. In order to get the relative numbers, we must first balance the chemical equation. This is not always an easy task. The first thing you have to remember when doing it, is that the number of atoms of each element on the left must be equal to the number of atoms of the element on the right. The coefficients in the balanced equation are the relative numbers. For example,

$2\ C_2H_{6\,(g)} + 7\ O_{2(g)} \longrightarrow 4\ CO_{2(g)} + 6\ H_2O(g)$

The balanced equation of the reaction between ethane and oxygen, gives you a lot of valuable information

* 2 molecules $C_2H_{6\,(g)}$ + 7 molecules $O_{2(g)} \longrightarrow$ 4 molecules $CO_{2(g)}$ + 6 molecules $H_2O(g)$

* 2 mol $C_2H_{6\,(g)}$ + 7 mol $O_{2(g)} \longrightarrow$ 4 mol $CO_{2(g)}$ + 6 mol $H_2O(g)$

* 60g $C_2H_{6\,(g)}$ + 224g $O_{2(g)} \longrightarrow$ 176g $CO_{2(g)}$ + 108g $H_2O(g)$

* 284g reactants $\longrightarrow$ 284g products

In a balanced equation, the number of moles of one substance is stoichiometrically equal to the number of moles of any other substance. These quantitative relations are expressed by mole ratios. Therefore, for the reaction above

2 mol of C_2H_6 is stoichiometrically equal to 4 mol CO_2
2 mol of C_2H_6 is stoichiometrically equal to 6 mol H_2O
2 mol of C_2H_6 is stoichiometrically equal to 7 mol O_2

and so on.
To write mole ratios we use the notation $n(C_2H_6): n(O_2) = 2:7$ or

$$\frac{n(C_2H_6)}{n(O_2)} = \frac{2}{7}$$

Sample problem. How many moles of oxygen are consumed for the reaction $2NO + O_2 \longrightarrow 2NO_2$, when 15 mol of NO_2 are produced? To solve the problem, we have to find the molar ratio between oxygen and nitrogen dioxide.

$\frac{n(O_2)}{n(NO_2)} = \frac{1}{2}$, replace 10 mol NO_2 in the ratio $\frac{n(O_2)}{0\ \text{mol}} = \frac{1}{2}$ and calculate consumed moles oxygen

This sample problem can be extended by asking what mass of oxygen is needed for the reaction? Knowing how many moles of oxygen are consumed, we can easily calculate the mass of oxygen for the reaction.

$M(O_2) = 2A_r(O) = 2.16 = 32$ g/mol , therefore $m(O_2) = M(O_2).\ n(O_2) = 32.5 = 160$g

In order to calculate the masses of reactants or products, we have to follow the sequence

1. Write and balance the equation of the reaction
2. Convert known masses for the substances to moles if necessary
3. Use the balanced equation for mole ratios
4. Use the mole ratio to calculate the moles of the reactants or the products
5. Convert from moles back to grams if necessary.

Problem 1 Balance the equations and write the mole ratios

a) $Ca + O_2 \longrightarrow CaO$

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b) $SO_2 + O_2 \longrightarrow SO_3$

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c) $NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + H_2O$

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d) $NH_4OH + H_2SO_4 \longrightarrow (NH_4)_2SO_4 + H_2O$

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Problem 2. Magnesium is very important for many systems in the human body, especially for the nervous system and the muscles. It can react with oxygen forming an oxide which is used as an antacid or laxative. Write the chemical equation of the reaction. The amount of substance of magnesium oxide produced is 10 mol.

a) Determine the mass (g) of Mg that yields 10 mol MgO.
b) Determine the mass (kg) of O_2 that yields 12 mol MgO.
c) Determine the mass (g)of MgO formed from 5 mol Mg.

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b) ....
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Problem 3. Calcium carbonate reacts with hydrochloric acid at STP

$CaCO_3 + HCl \longrightarrow CaCl_2 + CO_2 + H_2O$

It's a test reaction for carbonates because of the produced CO_2. Balance the equation and calculate the volume (L) of CO_2, if you know that the mass of HCl needed for the reaction is 10g.

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Problem 4. Ammonia is produced from hydrogen and nitrogen according to the following unbalanced equation $N_2 + H_2 + NH_3$. Calculate the mass (kg) and the volume (L) of ammonia produced at STP if 6 moles of hydrogen reacted?

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Problem 5. When 4 grams of iron react with hydrochloric acid, iron chloride and hydrogen are produced. Write and balance the equation for the reaction. Calculate the mass (g) of $FeCl_2$. Determine the volume (L) of hydrogen at STP.

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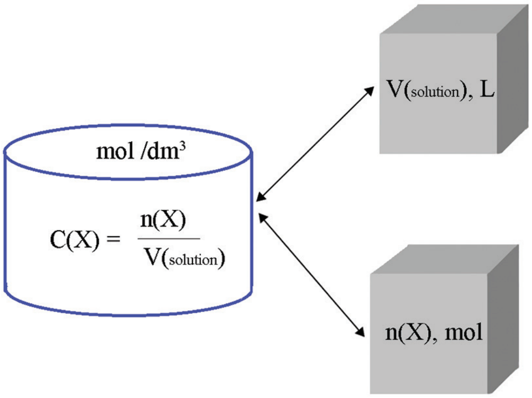
Molar concentration

16

Each solution contains a solute (the dissolved substance) and a solvent. For dissolved substances, we need to know the number of moles present in a certain volume of the solution in order to find the concentration and vice versa. One way to express concentration is molarity of a solution.
Molar concentration (c), or molarity is the number of moles of solute per exactly one liter (dm^3) of solution (mol/ dm^3). The notation 2 mol/ dm^3 and 2M are the same thing.



Sample problem 1. How many moles of hydrogen chloride are in 500 mL of 0.5 M solution of hydrochloric acid?
First we have to convert the volume from mL to L. 500 mL x 1L/ 1000mL= 0.5 L.
The equation for concentration can be rearranged to solve for the solute moles:
$n(HCl) = c(HCl) \times V_{(solution)} = 0.5\ mol/\cancel{L} \times 0.5\ \cancel{L} = 0,25\ mol$

Sample problem 2. What is the concentration of 98 g H_2SO_4 in 0,5 L of solution?
First we have to convert the mass into moles.

$$n(H_2SO_4) = \frac{m\ (H_2SO_4)}{M(H_2SO_4)}$$

$$M(H_2SO_4) = 2A_r\ (H) + A_r(S) + 4A_r(O)$$
$$= 2.1 + 32 + 4.16 = 98\ g/mol$$

$$n(H_2SO_4) = \frac{98\ \cancel{g}}{98\ \cancel{g}/mol}$$

$$n(H_2SO_4) = 1\ mol$$

$$c(H_2SO_4) = \frac{n\ (H_2SO_4)}{V_{(solution)}}$$

$$c(H_2SO_4) = \frac{1\ mol}{0,5\ L}$$

$$c(H_2SO_4) = 2\ mol/\ L$$

16

Molar concentration

Problem 1. Calculate the molar concentration (mol/L) for the following solutions

a) 25 g sodium hydroxide in 800 mL of solution

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b) 1,250 g $CuSO_4$ in 0,475 L of solution

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c) 2g potassium iodide in 250 mL of solution

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Problem 2. Calculate the mass (g) of solute present in each of the following solutions

a) 0.350 L of 0,5 M $KMnO_4$ solution

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b) 280 mL of 2,5 M KNO_3 solution

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c) 1700 mL of 1M C_2H_5OH solution

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Problem 3. Calcium reacts with 100 mL 2M hydrochloric acid. The products of the reaction are calcium (II) cloride and hydrogen.

a) Write the chemical equation for the process and balance it.

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b) Calculate the mass (g) of calcium and the masses of the products

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c) What is the volume (L) of hydrogen at STP?

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Problem 4. * Metamizole sodium $C_{13}H_{16}N_3NaO_4S$ was synthesized in 1920. It's a substance used as an active ingredient in painkillers and antipyretic medicines. One of the trade names used for it is Hexalgin. In pharmacy the product is usually sold as 20 mL solution. It contains 500 mg metamizole sodium in 1 mL of the solution. Calculate the concentration (mol/L) of the solution. (1mg = 0,001 g)

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Problem 5. How many grams of barium sulfate will be produced if 200 mL of a 1M solution of barium chloride is mixed with 200 mL of 1M solution of sulfuric acid?

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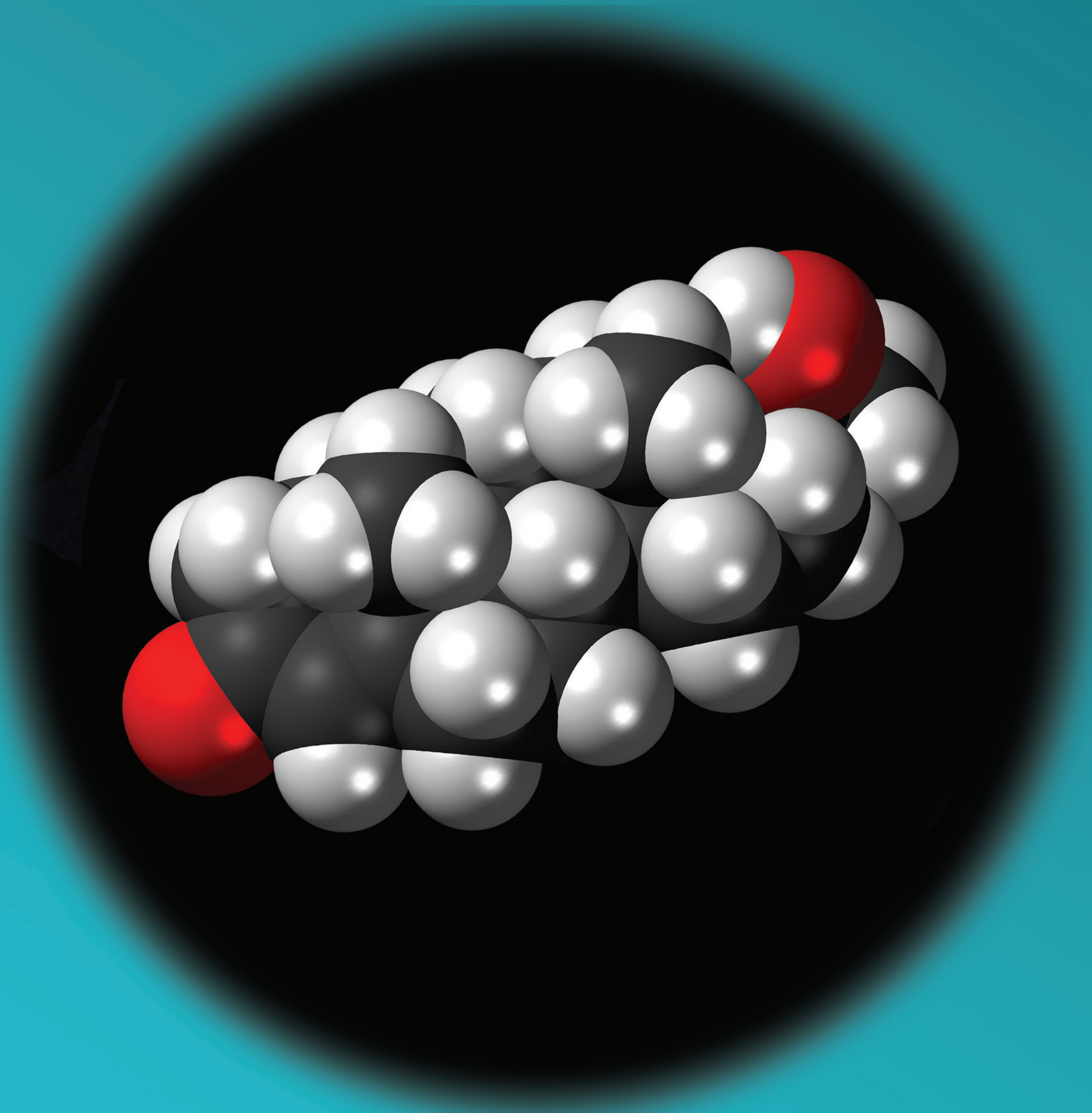
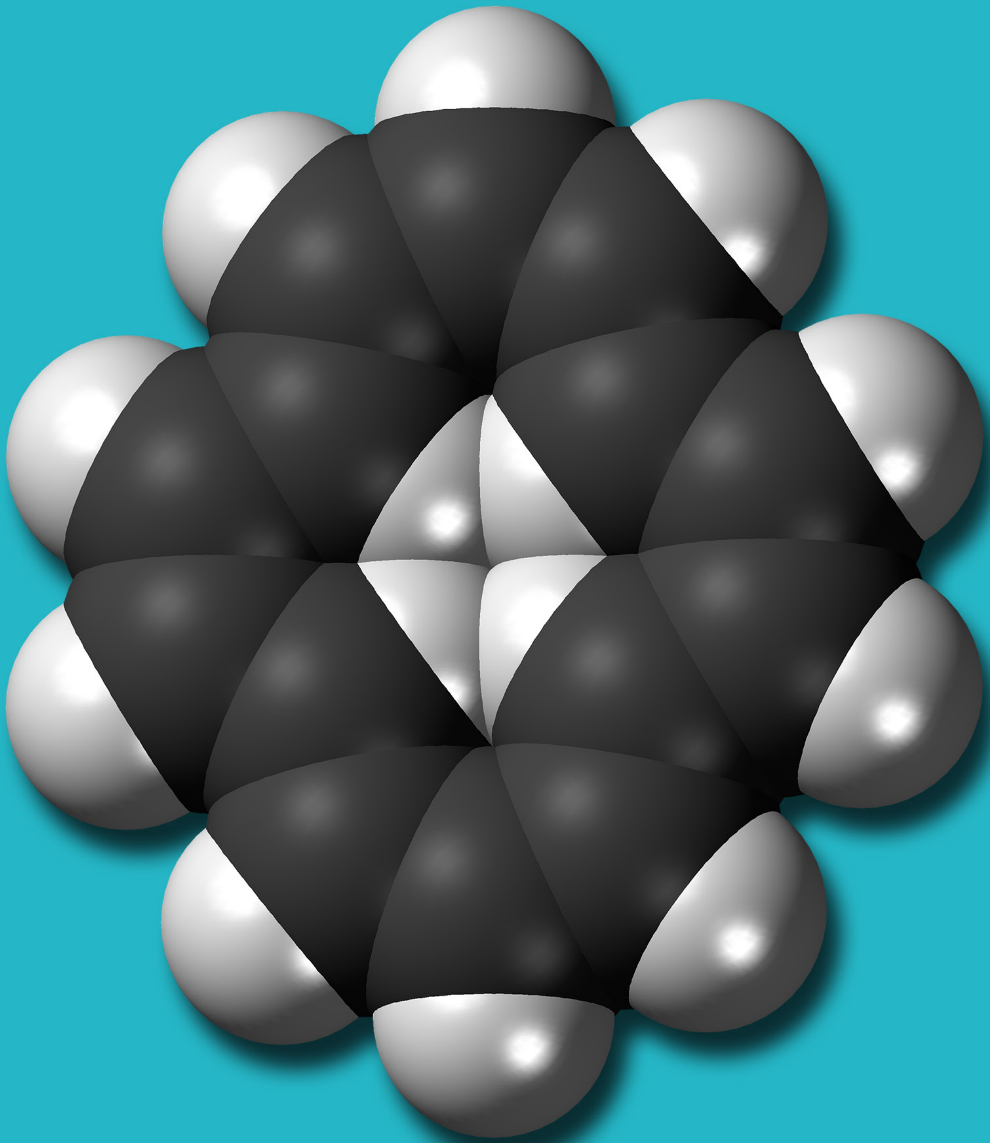
ORGANIC CHEMISTRY



Part V

Hydrocarbons



Basic concepts

17

The carbon atom

Chemistry is part of our everyday life undoubtedly. Everything from the coffee we have in the morning to the food we eat to nurture our bodies, the medicine we take when we have a headache, the soap we use to wash our hands and so on, they are all chemical products. In chemistry, substances can be divided into two large groups called inorganic and organic compounds. While inorganic compounds may vary in composition a lot and can be composed from almost every element in the periodic table, organic compounds contain mainly carbon and a few other elements like hydrogen, oxygen, sulfur and nitrogen.

Figure 1
Friedrich Wöhler

Early chemists thought that organic compounds could be synthesized only in living creatures: plants, animals, humans. They thought their existence is due to the presence of vital force acting in them. Later on, this idea was disproven by a German chemist named Wohler (Figure 1) who synthesized by accident the organic compound urea in a his laboratory. Since then, the organic chemistry begun to flourish and develop.

Today nearly 16 million organic compounds are known, as opposite to about 600 000 inorganics. Why when the building blocks of organic compounds are only few elements there is such a large variety of them? The answer is hidden in the uniqueness of the carbon atom. The first reason is that the carbon atom with its four valence electrons, can form four covalent bonds with other atoms including other carbon atoms. The four unpaired electrons can form stable single (C–C), double (C=C) and triple bonds (C ≡ C). And the second reason is that the carbon atoms can form long chains. In Figure 2 you can see different types of carbon chains

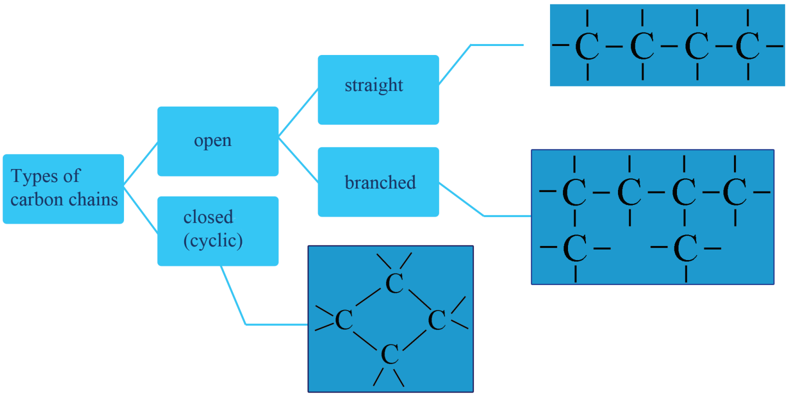


Figure 2

When the bonds in the carbon chain are all single, four types of carbon atoms can be present (Figure 3):

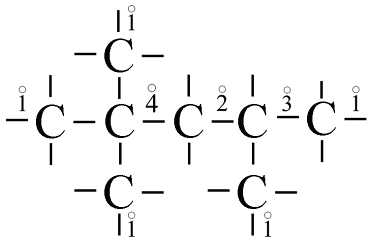
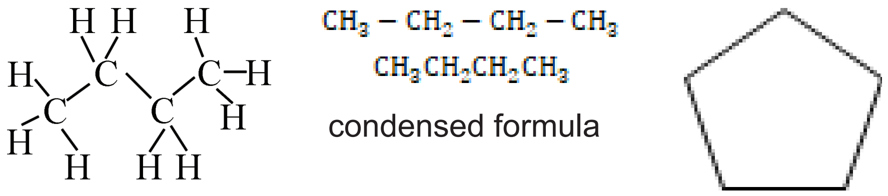


Figure 3

- ✓ Primary $\overset{\circ}{1}$: a carbon atom bonded to only one other carbon atom
- ✓ Secondary $\overset{\circ}{2}$: a carbon atom bonded to two other carbon atoms
- ✓ Tertiary $\overset{\circ}{3}$: a carbon atom bonded to three other carbon atoms
- ✓ Quaternary $\overset{\circ}{4}$: a carbon atom bonded to four other carbon atoms

Structural formulas

The molecular formula represents the elemental composition of a compound and the number of atoms of each element. For example, the molecular formula of propane is C_3H_8 and the molecular formula of benzene is C_6H_6. However, in order to understand the chemical properties of these compounds, we need to know their structural formulas. They represent the arrangement of atoms and bonds.
There are several ways you can write a structural formula. The most common types of formulas are shown in Figure 4.



dashed formula

condensed formula

bond-line (skeletal) formula

Figure 4

Basic concepts

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In organic chemistry, we mostly use condensed structural formulas since they represent all the information we have in the dashed structure in a more compact way (with less writing). In the condensed formula all hydrogen atoms bonded to a given carbon atom are written immediately after that atom symbol followed by a subscript showing the exact number of hydrogen atoms, for example $-CH_3$. The most commonly used formulas by organic chemists are the bond-line (skeletal) formulas. They lack the elements' atomic symbols representing the molecular skeleton with dashes.

Key terms

- carbon chains
- open
- closed
- straight
- branched chains
- primary
- secondary
- tertiary
- quaternary carbon atom
- structural formula
- dashed formula
- condensed formula
- bond line (skeletal formula)
- isomerism
- isomers

Isomers

In organic chemistry, compounds with the same molecular formula may have different chemical and physical properties. Such compounds are called *isomers*. Isomers have the same elemental composition and contain the same number of atoms of each element but they have different structure: the atoms are bonded to each other in a different manner. A substance with molecular formula C_4H_{10}, can form two different structures, e.g. has two isomers. The molecular formula of the ethyl alcohol is C_2H_6O. The dimethyl ether has the same molecular formula C_2H_6O yet they are two different compounds with different both physical and chemical properties due to their different structure.

CH_3CH_2OH ethyl alcohol

$CH_3 - O - CH_3$ dimethyl ether

Key terms: Condensed structural formula, isomers, skeletal structural formula, dashed structural formula.

Solve the problems below

Problem 1. Draw a carbon chain consisting of

a) four carbon atoms, one of them tertiary

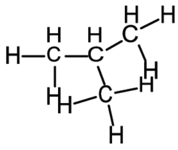
b) four carbon atoms, one of them quaternary and one tertiary

c) six secondary carbon atoms

d) two primary carbon atoms

Problem 2. Write the condensed and molecular formulas of each of the following structures

a)



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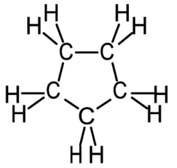
b)



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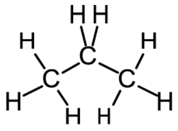
c)



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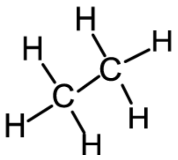
d)



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Problem 3. Write the skeletal formulas of each of the following structures

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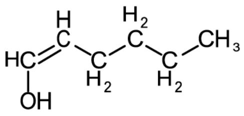

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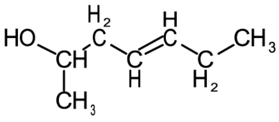

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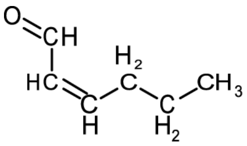

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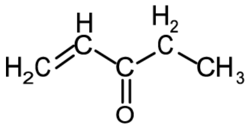
d)



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Problem 4. Which of the following formulas represent isomers? Write their molecular formulas.

a) CH_3CH_2OH and $CH_3CH_2CH_2OH$

b) $CH_3CHClCH_3$ and $CH_3CH_2CH_2Cl$

c) $CH_2 = CHCH_3$ and $CH \equiv CCH_3$

d) $CH_3CH_2CH_2CH_2OH$ and $CH_3OCH_2CH_2CH_3$

18

Saturated hydrocarbons. Alkanes

Introduction of hydrocarbons

Hydrocarbons are compounds of hydrogen and carbon. There are two types of hydrocarbons – saturated and unsaturated. Saturated hydrocarbons contain only carbon-carbon single bonds and the maximum possible numbers of hydrogen atoms. Unsaturated hydrocarbons have less hydrogen atoms than saturated hydrocarbons due to the presence of double or triple carbon – carbon bonds. In Figure 1 the classification of the hydrocarbons is shown.

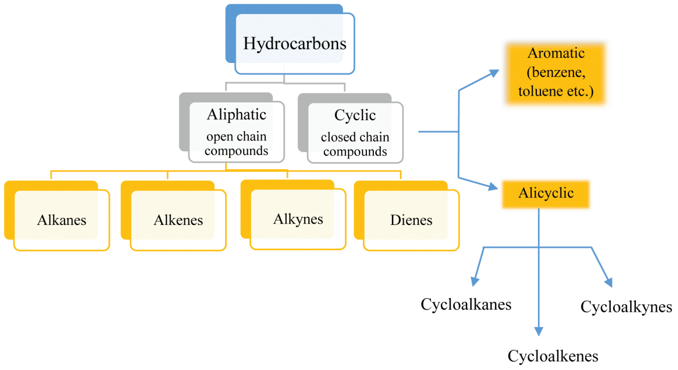


Figure 1

Alkanes – homologous series and nomenclature

Alkanes contain carbon atoms bonded to other carbon atoms or to hydrogen atoms by single covalent bonds. When carbon atoms are bonded in a continuous chain they are called normal, when a carbon atom is bonded to other three or four other carbon atoms the chain is branched. In the table are shown molecular formula, nomenclature and the structure of the first six normal alkanes.

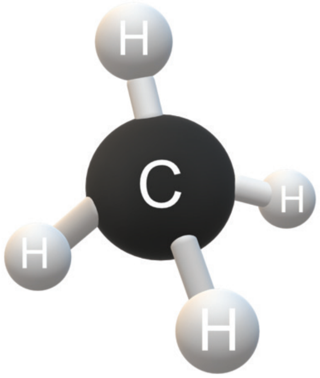


Figure 2
Methane

Molecular formula	IUPAC name	Structural formula
CH_4	methane	CH_4
C_2H_6	ethane	$CH_3 – CH_3$
C_3H_8	propane	$CH_3 – CH_2 –$ CH3
C_4H_{10}	butane	$CH_3 – CH_2 – CH_2 – CH_3$
C_5H_{12}	pentane	$CH_3 – CH_2 – CH_2 – CH_2 – CH_3$
C_6H_{14}	hexane	$CH_3 – CH_2 – CH_2 – CH_2 – CH_2 –CH_3$
C_nH_{2n+2}	alkane	–

Table 1

Saturated hydrocarbons. Alkanes

18

If we look at Table 1 more closely, we see that each compound differs from the one above or below with one $-CH_2$ unit. Series of compounds that differ with one or few $-CH_2$ units is called homologous series and the compounds are called homologues.

When the chain is branched, the group of carbon atoms attached to the main chain at the branching point is called alkyl group. In Table 2 are given the names of the first three alkyl groups.

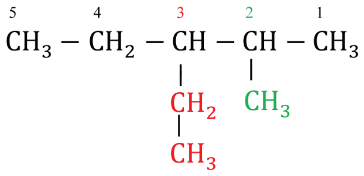
Alkyl group	Name
$-CH_3$	methyl
$-C_2H_5$	ethyl
$-C_3H_7$	propyl
$-C_nH_{2n+1}$	alkyl

Table 2

International Union of Pure and Applied Chemistry (IUPAC) set rules to name the organic compounds. If they are followed correctly, each organic compound has unique name. These rules are as follows:

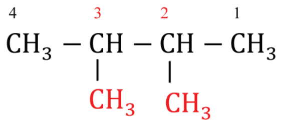
1. The longest carbon chain is used as a base. It is named like the alkane with the same number of carbon atoms (Table 2). The carbon atoms from the main chain are numbered from the end which is nearest to the branch.

2. If three or more of the same type of alkyl groups occur, the number of them is indicated by the prefix di-, tri- etc. There must be a number for each branch separated with commas. If the alkyl groups are different they are placed in alphabetical order. The numbers for the positions of the alkyl groups are placed immediately before the name of the group.



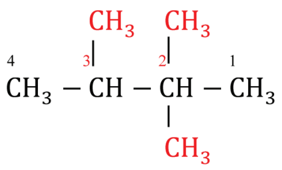
$$\begin{array}{ccccccccc} {}^{5} & & {}^{4} & & {}^{3} & & {}^{2} & & {}^{1} \\ CH_3 & - & CH_2 & - & CH & - & CH & - & CH_3 \\ & & & & | & & | & & \\ & & & & CH_2 & & CH_3 & & \\ & & & & | & & & & \\ & & & & CH_3 & & & & \end{array}$$

3- ethyl-2-methylpentane



$$\begin{array}{ccccccc} {}^{4} & & {}^{3} & & {}^{2} & & {}^{1} \\ CH_3 & - & CH & - & CH & - & CH_3 \\ & & | & & | & & \\ & & CH_3 & & CH_3 & & \end{array}$$

2,3- dimethylbutane

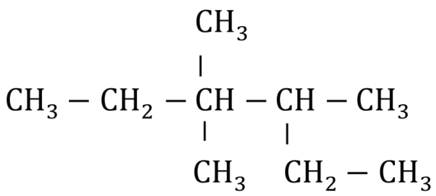


$$\begin{array}{ccccccc} & & CH_3 & & CH_3 & & \\ & & | & & | & & \\ {}^{4} & & {}^{3} & & {}^{2} & & {}^{1} \\ CH_3 & - & CH & - & CH & - & CH_3 \\ & & & & | & & \\ & & & & CH_3 & & \end{array}$$

2,2,3- trimethylbutane

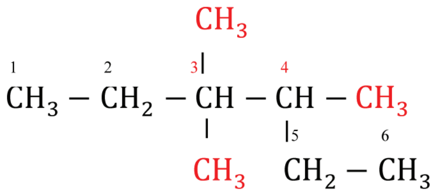
18 Saturated hydrocarbons. Alkanes

Sample problem: Name the following compound.



$$\begin{array}{ccccccccc} & & & & CH_3 & & & & \\ & & & & | & & & & \\ CH_3 & - & CH_2 & - & CH & - & CH & - & CH_3 \\ & & & & | & & | & & \\ & & & & CH_3 & & CH_2 - CH_3 & & \end{array}$$

The longest chain has six carbon atoms. The three methyl groups are located at positions 3,3 and 4. The name is 3,3,4-trimethylhexane.



$$\begin{array}{ccccccccc} & & & & CH_3 & & & & \\ & & & & {}^{3}| & & {}^{4} & & \\ \overset{1}{CH_3} & - & \overset{2}{CH_2} & - & CH & - & CH & - & CH_3 \\ & & & & | & & |_{5} & & \\ & & & & CH_3 & & CH_2 - \overset{6}{CH_3} & & \end{array}$$

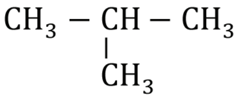
3,3,4 – trimethylhexane

Isomerism

As we said in the previous chapter, there are two hydrocarbons with the formula C_4H_{10}. When two compounds have the same molecular formula but differ in arrangement of the atoms and their physical and chemical properties, we call them *structural isomers*. The number of possible isomers increases with the number of carbon atoms in the chain.

$CH_3 - CH_2 - CH_2 - CH_3$

n-butane



$$\begin{array}{ccccc} CH_3 & - & CH & - & CH_3 \\ & & | & & \\ & & CH_3 & & \end{array}$$

Isobutane (2 – methylpropane)

Problem 1. Write the condensed formula for each of the following compounds

a) 2,3,3-trimethylpentane ....

b) 4-methylheptane ....

c) 2,5-dimethylheptane ....

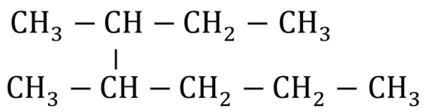
d) 2,2,3,3-tetramethylbutane ....

e) 3-ethyl-2,5-dimethylhexane ....

f) 2-bromo-3-ethylpentane ....

Problem 2. Name each compounds according to the IUPAC nomenclature.

a)



$$\begin{array}{ccccccccc} CH_3 & - & CH & - & CH_2 & - & CH_3 & & \\ & & | & & & & & & \\ CH_3 & - & CH & - & CH_2 & - & CH_2 & - & CH_3 \end{array}$$

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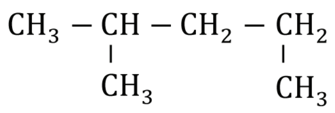
b)



$$\begin{array}{ccccccc} CH_3 & - & CH & - & CH_2 & - & CH_2 \\ & & | & & & & | \\ & & CH_3 & & & & CH_3 \end{array}$$

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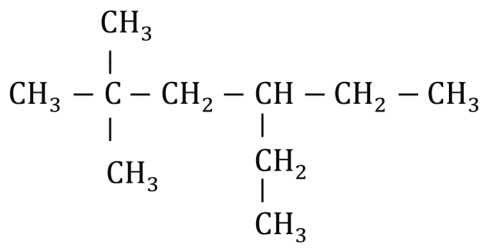
c)



$$\begin{array}{ccccccccccc} & & CH_3 & & & & & & & & \\ & & | & & & & & & & & \\ CH_3 & - & C & - & CH_2 & - & CH & - & CH_2 & - & CH_3 \\ & & | & & & & | & & & & \\ & & CH_3 & & & & CH_2 & & & & \\ & & & & & & | & & & & \\ & & & & & & CH_3 & & & & \end{array}$$

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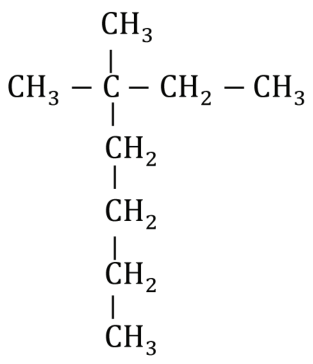
d)



$$\begin{array}{ccccccc} & & CH_3 & & & & \\ & & | & & & & \\ CH_3 & - & C & - & CH_2 & - & CH_3 \\ & & | & & & & \\ & & CH_2 & & & & \\ & & | & & & & \\ & & CH_2 & & & & \\ & & | & & & & \\ & & CH_2 & & & & \\ & & | & & & & \\ & & CH_3 & & & & \end{array}$$

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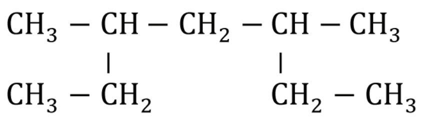

$$\begin{array}{ccccccccc} CH_3 & - & CH & - & CH_2 & - & CH & - & CH_3 \\ & & | & & & & | & & \\ CH_3 & - & CH_2 & & & & CH_2 & - & CH_3 \end{array}$$

Problem 3. Write all the possible structural isomers of pentane (using condensed formulas) and name them according to the IUPAC nomenclature.

Physical and chemical properties of alkanes

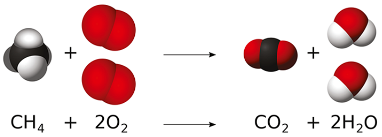

Figure 3
Methane combustion

Alkanes are insoluble in water and have lower density compared to it. They are compounds with low boiling points, which increases with molecular weight of the alkane. The first four homologues are gases, followed by liquids and solids. They are quite stable compounds and therefore less reactive. There are two characteristic reactions – halogenation and combustion.

Problem 4. The halogenation of alkanes is a substitution reaction in which a hydrogen atom in the alkane is replaced by another atom. The reaction occurs in the presence of heat or UV light and continues until all hydrogen atoms in the molecule are replaced.

Write all the possible products of the chlorination of

a) methane and name them

b) ethane and name them

Problem 5. Write the chemical equation of the combustion of the hydrocarbons. The products in each case are the same: carbon dioxide and water. Alkanes are used for fuels because of the high amount energy released during the reaction.

a) methane's combustion………………………………………………..
b) ethane's combustion…………………………………………………
c) propane's combustion…………………..…………………………
d) calculate the mass of the water produced by the combustion of 52g propane
e) calculate the mass of oxygen needed for the combustion of 2g ethane
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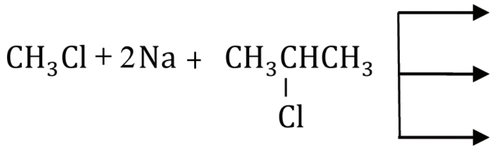
Key terms

- Hydrocarbons
- saturated hydrocarbons
- alkanes
- homologous
- nomenclature
- IUPAC
- structural isomers
- combustion
- substitution reaction,
- halogenation
- Wurtz reaction
- freon
- environmental protection

Problem 6. Choose the right words in the text
Wurtz synthesis reaction is a coupling reaction. It is a reaction between ………………… and ………………………… in the presence of dry ether. The product is an …………………. containing twice the number of carbon atoms in the monohalogenoalkane. When two……………………………halogenoalkanes react in Wurtz reaction all the possible alkanes are produced.
Write the condensed formulas of the products on the diagram



$$CH_3Cl + 2Na + \underset{\displaystyle Cl}{\underset{|}{CH_3CHCH_3}}$$

18

Saturated hydrocarbons. Alkanes

Problem 6. Write the condensed structural formula of 3-ethyl-2,2-dimethylhexane. Which of its isomers is a normal alkane?

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Figure 5
Freon

Project. Freon free

1. What is Freon?
2. What is it used for?
3. How it affects the planet Earth and our lives?
4. Environmental protection

Unsaturated hydrocarbons. Alkenes

19

Alkenes – homologous series and nomenclature

Alkenes are unsaturated hydrocarbons that contain carbon-carbon double bond (C=C) and two hydrogen atoms less than alkanes. The simplest alkene and first in the homologues series is ethene (Figure 1). The series are very similar to that of alkanes. In Table 1 the molecular formula, nomenclature and the structural formula of the first three normal alkenes are given.

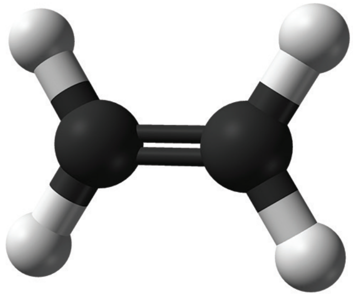
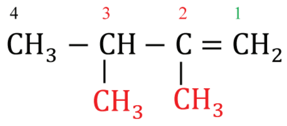


Figure 1
Ethene

Molecular formula	**IUPAC name**	**Structural formula**
C_2H_4	Ethene	$CH_2 = CH_2$
C_3H_6	Propene	$CH_2 = CH – CH3$
C_4H_8	But-1- ene But-2- ene	$CH_2 = CH – CH_2 – CH_3$ $CH_3 – CH = CH – CH_3$
C_nH_{2n}	alkene	-

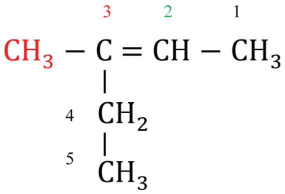
Table 1

The IUPAC names of normal and branched alkenes are brought out from that of the alkanes' names where the suffix -ane is replaced with -ene. The name must contain the location of the double bond and numbering of the main chain starts from the end, which is closer to the double bond.



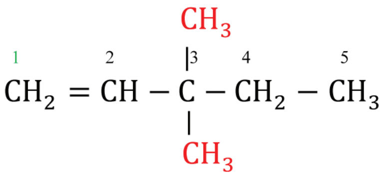
$$\overset{4}{CH_3} - \underset{\underset{CH_3}{|}}{\overset{3}{CH}} - \underset{\underset{CH_3}{|}}{\overset{2}{C}} = \overset{1}{CH_2}$$

2,3- dimethylbut-1-ene



$$CH_3 - \underset{\underset{\underset{\underset{{}^{5}\,CH_3}{|}}{{}^{4}\,CH_2}}{|}}{\overset{3}{C}} = \overset{2}{CH} - \overset{1}{CH_3}$$

3- methylpent-2-ene



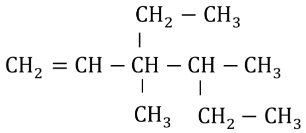
$$\overset{1}{CH_2} = \overset{2}{CH} - \underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|3}}{C}} - \overset{4}{CH_2} - \overset{5}{CH_3}$$

3,3- dimethylpent-1-ene

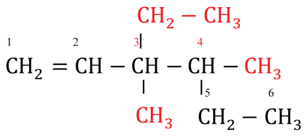
19

Unsaturated hydrocarbons. Alkenes

Sample problem Name the following compound.



$$CH_2 = CH - \overset{\displaystyle CH_2 - CH_3}{\underset{\displaystyle CH_3}{CH}} - \underset{\displaystyle CH_2 - CH_3}{CH} - CH_3$$



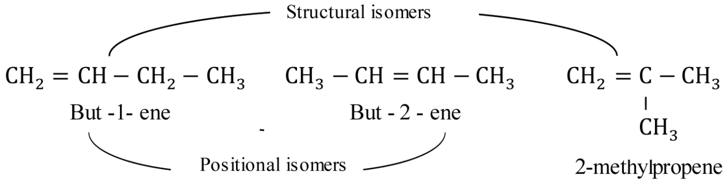
$$\overset{1}{CH_2} = \overset{2}{CH} - \overset{\displaystyle CH_2 - CH_3}{\underset{\displaystyle CH_3}{\overset{3}{CH}}} - \overset{4}{\underset{\displaystyle \overset{5}{CH_2} - \overset{6}{CH_3}}{CH}} - CH_3$$

3-ethyl -3,4 – dimethylhex-1-ene

The longest chain has six carbon atoms. Two methyl groups are located at positions 3 and 4 and one ethyl group on position 3. The double bond is located on the first carbon atom. The IUPAC name is 3-ethyl-3,4-dimethylhex-1-ene.

Isomerism

Alkenes have structural isomerism like alkanes. There is also another type of isomerism present – positional isomerism. It depends on the position of the double bond in the carbon chain. All the possible isomers, both structural and positional for C_4H_8 are



Structural isomers

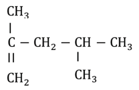
$CH_2 = CH - CH_2 - CH_3$ But -1- ene

$CH_3 - CH = CH - CH_3$ But - 2 - ene

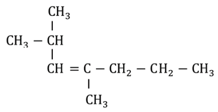
$CH_2 = \underset{\displaystyle CH_3}{C} - CH_3$ 2-methylpropene

Positional isomers

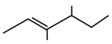
Problem 1. Connect the structural formulas to the correct IUPAC names.

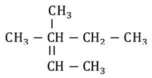


$$\underset{\displaystyle \| \atop CH_2}{\overset{\displaystyle CH_3}{C}} - CH_2 - \underset{\displaystyle CH_3}{CH} - CH_3$$



$$\overset{\displaystyle CH_3 - \overset{\displaystyle CH_3}{CH}}{CH} = \underset{\displaystyle CH_3}{C} - CH_2 - CH_2 - CH_3$$





$$CH_3 - \overset{\displaystyle CH_3}{\underset{\displaystyle \| \atop CH - CH_3}{CH}} - CH_2 - CH_3$$

3,4 – dimethylhex – 3 – ene

But – 2 – ene

3,4 – dimethylhex – 2 – ene

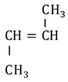
3 – ethyl – 2 – methylpent – 2 – ene

4 – methyl – pent – 1 – ene

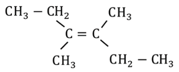
3,3 – dimethylpent – 2 – ene

2,3 – dimethylbut – 2 – ene

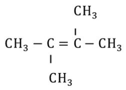
2,4 – dimethylhept – 3 – ene



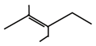
$$\underset{\displaystyle CH_3}{CH} = \overset{\displaystyle CH_3}{CH}$$



$$\begin{matrix} CH_3 - CH_2 & & CH_3 \\ & C = C & \\ CH_3 & & CH_2 - CH_3 \end{matrix}$$



$$CH_3 - \underset{\displaystyle CH_3}{C} = \overset{\displaystyle CH_3}{C} - CH_3$$



Problem 2. Which of the following compounds denoted with molecular formula are alkenes:

C_2H_6, $C_6H_{12,}$ $C_6H_{6,}$ C_2H_6O, $C_8H_{18,}$ $C_{13}H_{26,}$ $C_2H_{2,}$ $C_4H_{8,}$ $C_3H_{6,}$ $C_5H_{12,}$ C_2H_4O, C_5H_{10}

Which one of them is pentene? The possible structural and positional isomers of pentene are five. Draw their structural formulas and name them according to the IUPAC nomenclature.

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Physical and chemical properties of alkenes

Alkanes and alkenes have similar physical properties. The boiling and melting points of alkenes increase with the number of carbon atoms in their chains. The physical state changes accordingly from gas through liquid to solid. Alkenes are more reactive than alkanes and their chemical properties are defined from the double bond (C=C). The most common reactions for them as unsaturated hydrocarbons are addition reactions (Figure 2). In addition reactions, a small molecule is added to the multiple bond. As a result, the bond breaks and the atoms of the small molecule join the atoms of the multiple bond. The product of addition reactions is only one.

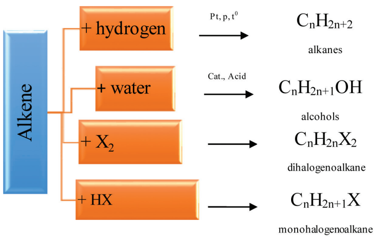


Figure 2
Addition reactions
of alkenes

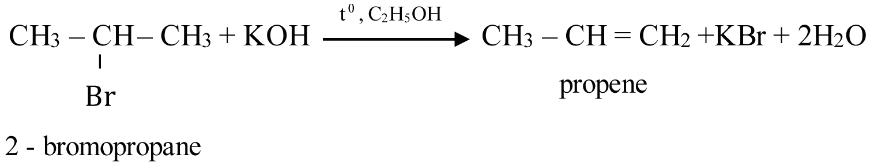
19 Unsaturated hydrocarbons. Alkenes

Alkenes synthesis reactions

Alkenes are produced in two ways – dehydrogenation and dehydrohalogenation both reactions of elimination.

$$CH_3 - CH_2 - CH_3 \xrightarrow{t^0,\ cat.} CH_2 = CH - CH_3 + H_2$$

propane propene



$$\underset{\substack{|\\ Br}}{CH_3 - CH - CH_3} + KOH \xrightarrow{t^0,\ C_2H_5OH} CH_3 - CH = CH_2 + KBr + 2H_2O$$

2 - bromopropane propene

Problem 3. Using Figure 2 write the equations of the following reactions for ethene. Name the products according to the IUPAC nomenclature.

a) Hydrogenation

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b) Hydration

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c) Halogenation

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d) Hydrohalogenation

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Figure 3
Vladimir Markovnikov

Problem 4. There are two types of alkenes – symmetrical and unsymmetrical. Unsymmetrical alkenes have a different number of hydrogen atoms attached to double bonded carbon atoms. The addition of hydrogen halides to unsymmetrical alkene produces two compounds. One of the compounds is the major product because it is dominant in the mixture. In order to write the correct equation, we must follow Markovnikov's rule. Markovnikov's rule states that the hydrogen atom from the hydrogen halide is added to the carbon atom from the double bond that has a greater number of hydrogen atoms.

a) but-1-ene reacts with HBr according to Markovnikov's rule. Write the structural formulas of all the products and name them using the IUPAC nomenclature.

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Key terms

- unsaturated hydrocarbons
- double bond
- positional isomers
- symmetrical alkenes
- unsymmetrical alkenes
- addition reactions
- Markovnikov's rule
- polymerisation
- polymers
- teflon
- polyvinyl chloride

b) Propene reacts with HCl according to Markovnikov's rule. Write the structural formulas of all products and name them using the IUPAC nomenclature.

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Problem 5. There are two tubes on the table in the lab. One of them is filled with propane and the other one with propene which both are colorless gases. You have the following reagents: litmus, hydrochloric acid, sodium hydroxide, bromine water (aqueous solution of Br_2). Which one are you going to use to distinguish the two gases? Explain why and write down all chemical equations.

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Problem 6. Everyday life and polymers

Another important addition reaction is polymerization. Small molecules called monomers can add together to form polymer with large molecular mass. For example, worldwide used polymer called polyethylene is produced in a polymerization reaction as follows:

19 Unsaturated hydrocarbons. Alkenes

$$CH_2 = CH_2 \xrightarrow[t^0,\ p,\ cat]{\text{Polymerysation}} -\!\!\left[CH_2 - CH_2 \right]\!\!-_n$$

Ethene Polyethylene

PVC pipes

About 40 million tons of polyvinylchloride (PVC, Vynyl) are produced each year. After polyethylene and polypropylene, it is the third most widely used plastic.

a) Write the chemical equation for producing polyvinylchloride from chloroethene.

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b) Find information about the applications of polyvinylchloride and how it affects our health and our planet.

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Project. Teflon – does it make us sick?

1. What is Teflon and how it is synthesized?
2. Applications
3. Health issues and safety recommendations.

Teflon fry pan Teflon jar Teflon band

Usages of Teflon

Unsaturated hydrocarbons. Alkynes

20

Alkynes – homologous series and nomenclature

Alkynes are unsaturated hydrocarbons that contain carbon-carbon triple bond (C≡C) and four hydrogen atoms less than alkanes. The simplest alkyne and first in the homologues series is ethyne (Figure 1). It is called acetylene as well. The series are very similar to that of alkanes. In Table 1 the molecular formula, nomenclature and the structural formula of first three normal alkynes are given.

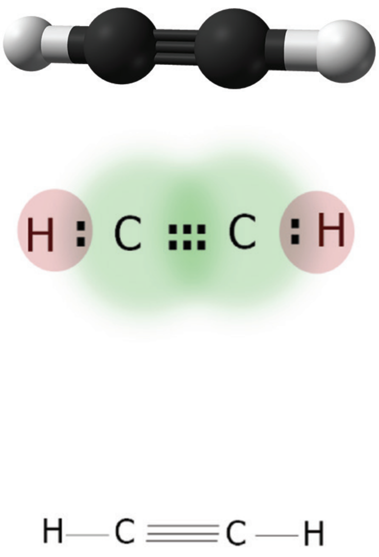
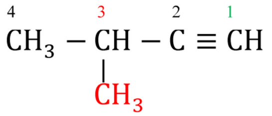


Figure 1
Ethyne

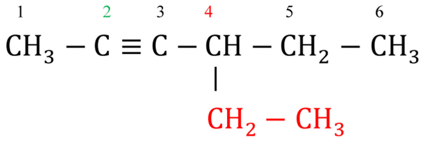
Molecular formula	**IUPAC name**	**Structural formula**
C_2H	Ethyne	$CH \equiv CH$
C_3H_4	Propyne	$CH \equiv C - CH_3$
C_4H_6	But-1- yne But-2- yne	$CH \equiv C - CH_2 - CH_3$ $CH_3 - C \equiv C - CH_3$
C_nH_{2n-2}	alkyne	–

Table 1



$$\overset{4}{CH_3} - \underset{\substack{|\\ CH_3}}{\overset{3}{CH}} - \overset{2}{C} \equiv \overset{1}{CH}$$

3 – methylbut – 1 – yne

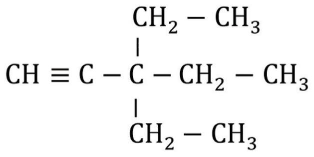


$$\overset{1}{CH_3} - \overset{2}{C} \equiv \overset{3}{C} - \underset{\substack{|\\ CH_2 - CH_3}}{\overset{4}{CH}} - \overset{5}{CH_2} - \overset{6}{CH_3}$$

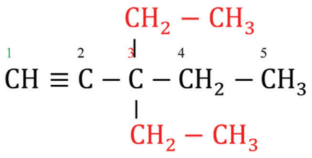
3 – ethylhex – 2 – yne

The IUPAC nomenclature is similar to that of alkenes and alkanes but the suffix is -yne which indicates that there is a triple carbon-carbon bond in the molecule. In order to name a compound, we must follow the same rules we used for alkanes and alkenes.

Sample problem Name the following compound



$$CH \equiv C - \underset{\substack{|\\ CH_2 - CH_3}}{\overset{\substack{CH_2 - CH_3\\ |}}{C}} - CH_2 - CH_3$$



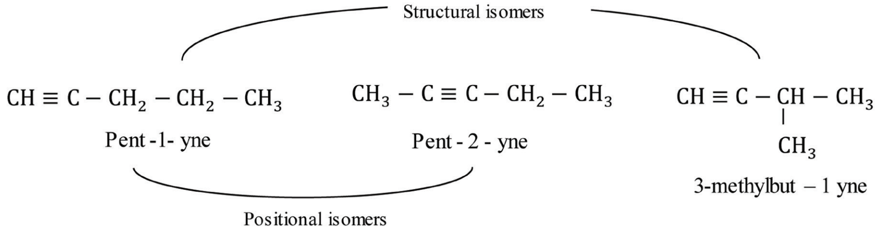
$$\overset{1}{CH} \equiv \overset{2}{C} - \underset{\substack{|\\ CH_2 - CH_3}}{\overset{\substack{CH_2 - CH_3\\ |\\ 3}}{C}} - \overset{4}{CH_2} - \overset{5}{CH_3}$$

3, 3 – diethylpent – 1 – yne

The longest chain has five carbon atoms. Two ethyl groups are located at positions 3. The location of the triple bond is on the first carbon atom. The name is 3,3-diethylpent-1-yne.

Isomerism

Alkynes have structural and positional isomerism. Structural and positional isomers for C_5H_8 are:



Problem 1. Name each of the following compounds using the IUPAC nomenclature or write the structural formula

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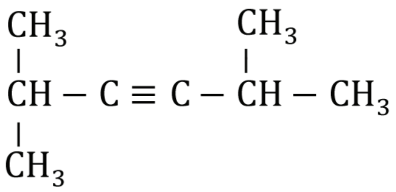

$$\underset{\displaystyle CH_3}{\overset{\displaystyle CH_3}{CH}} - C \equiv C - \overset{\displaystyle CH_3}{CH} - CH_3$$

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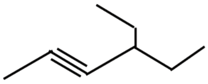
b) 2,2,5-trimethylhex-3-yne ....

c)



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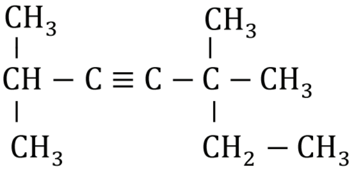
d) 3,4-dimethylpent-1-yne ....

e)



$$\underset{\displaystyle CH_3}{\overset{\displaystyle CH_3}{CH}} - C \equiv C - \underset{\displaystyle CH_2 - CH_3}{\overset{\displaystyle CH_3}{C}} - CH_3$$

....

f) 4-ethyloct-2-yne ....

Problem 2. Write all possible positional and structural isomers of hexyne and name them according to the IUPAC nomenclature.

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Key terms

- Alkynes
- triple bond
- elimination reactions
- pyrolysis

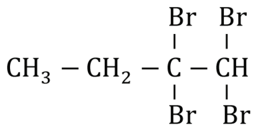
Physical and chemical properties of alkynes

The first three homologues are gases, from C_5 to C_{13} are liquids and above C_{14} solids. The boiling and melting points increase with the number of carbon atoms in the chain. They have a lower density than water and are insoluble in it. They are soluble in organic solvents. The typical chemical reactions for alkynes are addition reactions to the triple bond. They can add two more moles of reagent compared to alkenes. Carbon dioxide and water are the products of the combustion of alkynes.

Problem 3. Complete the missing parts in the equations, name all the compounds using the IUPAC nomenclature and balance the equations.

a) $CH \equiv C-CH_3 + \ldots\ldots\ldots\ldots \xrightarrow{t^0,\ p,\ cat} CH_3-CH_2-CH_3$

b)………………… + Br_2 $\longrightarrow$



$$CH_3-CH_2-\underset{Br}{\overset{Br}{C}}-\underset{Br}{\overset{Br}{CH}}$$

c) $CH \equiv CH + H_2O \longrightarrow$

d) $CH \equiv CH + \ldots\ldots\ldots\ldots \longrightarrow CO_2 + H_2O$

e) Acetylene burns easily and the flame is hot. It’s used for welding and cutting metal. A sample of C_2H_2 has a volume of 175 L at STP. Calculate how many moles of the gas are present in the sample? What is the volume of the resulted carbon dioxide at STP?

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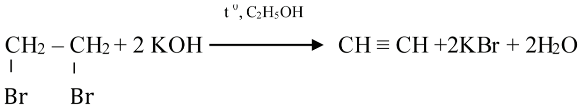
Alkynes synthesis reactions

Elimination reaction between halogenoalkanes and sodium or potassium hydroxide dissolved in ethanol produce alkynes



$$\underset{Br}{CH_2} - \underset{Br}{CH_2} + 2\,KOH \xrightarrow{t^0,\,C_2H_5OH} CH \equiv CH + 2KBr + 2H_2O$$

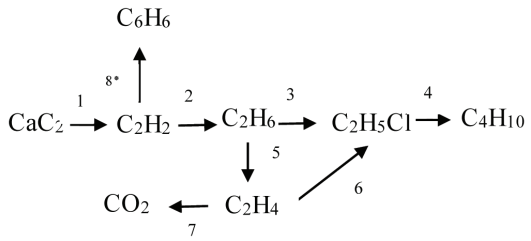
1,2 - dibromoethane

Other methods chemists use to produce ethyn are reaction between calcium carbide and water and methane’s pyrolysis.

$$CaC_2 + 2\,H_2O \longrightarrow C_2H_2 + Ca(OH)_2$$

$$2CH_4 \xrightarrow{2000^0C} C_2H_2 + 3H_2$$

Problem 5. Write down all chemical equations (1 – 8) for the reactions given in the figure.



1. ....
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3. ....
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6. ....
7. ....
8. ....

a) Write the IUPAC names of the products.

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b) Determine the reactions type: substitution, addition, combustion.

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21

Aromatic compounds. Benzene

Aromatic compounds

In the 19th century, organic chemists, isolated compounds from plants and oils and they had a pleasant fragrance. That's why they called them aromatic (Latin *aroma – fragrance)*. Over the years, they found out that all of these aromatic compounds contain the same specific structure – a benzene ring. With the development of organic chemistry and organic synthesis, it was found that aromatic compounds are a large family of organic compounds which are better classified by structure than by aroma (in fact many aromatic compounds have very unpleasant aroma). Therefore, aromatic compounds are all compounds that contain aromatic ring. A very important example of an aromatic ring is the benzene structure.

Benzene – structure and nomenclature

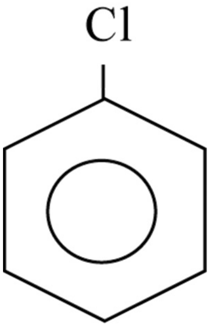


Figure 1
Chlorobenzene

Benzene is one of the simplest aromatic hydrocarbon. It contains six carbon atoms attached to each other with covalent bonds forming a hexagon. Each carbon atom has one unpaired electron and all six electrons form what is called a delocalized bond. This bond is shared between all carbon atoms and therefore the benzene molecule is different from that of alkenes. All carbon – carbon bonds in benzene are equivalent. That is not the case in the hexene molecule for example. The IUPAC nomenclature for aromatic compounds with benzene rings is the following: simply add the names of the substituents as a prefix to the name of benzene (for example, chlorobenzene (Figure 1).

Figure 2
August Kekulé
1829 – 1896

There are several ways chemists use to represent the benzene's structural formula. Most commonly, they use skeletal formulas like the ones in Figure 3.

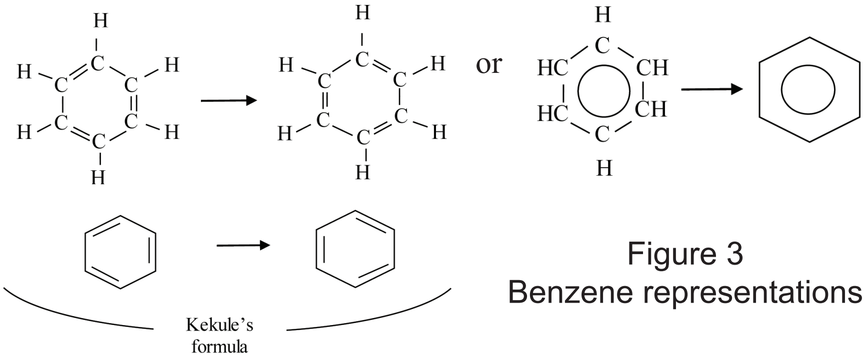


Figure 3
Benzene representations

Aromatic compounds. Benzene

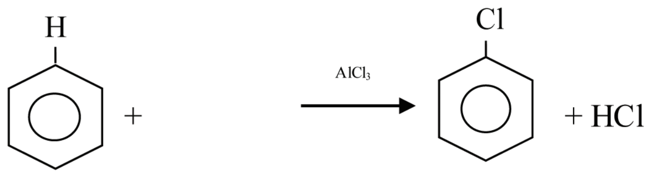
21

Physical and chemical properties

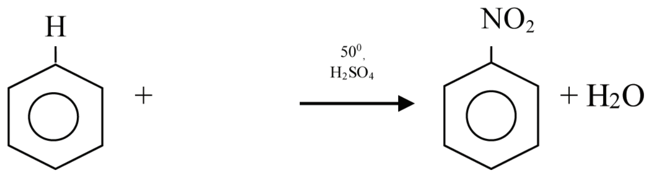
Benzene is a colorless, flammable liquid with gasoline like odor, carcinogen and slightly soluble in water. The reactions typical for benzene are substitution reactions. Addition reactions occur but they are slightly difficult. In substitution reactions one hydrogen atom from the ring is replaced with another atom or atomic group. The addition reactions produce cycloalkanes and derivatives of cycloalkanes.

Problem 1. Complete the equations using the following reagents HCl, H_2, H_2O, HNO_3, Br_2, $Cl_{2,}$ O_2 and name the products applying the IUPAC rules.

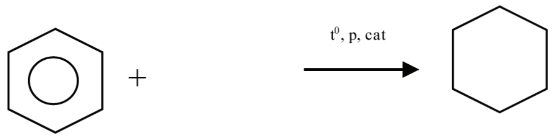
a)



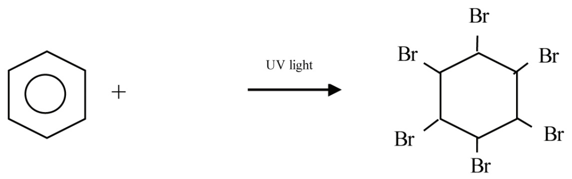
b)



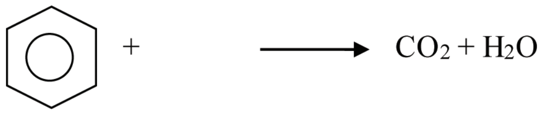
c)



d)



e)



Derivatives of benzene

When one or more hydrogen atoms in benzene's ring are replaced by different alkyl groups, derivatives of benzene are formed. They could be monoalkylbenzenes, dialkylbenzenes, etc. (Figure 4).

21

Aromatic compounds. Benzene

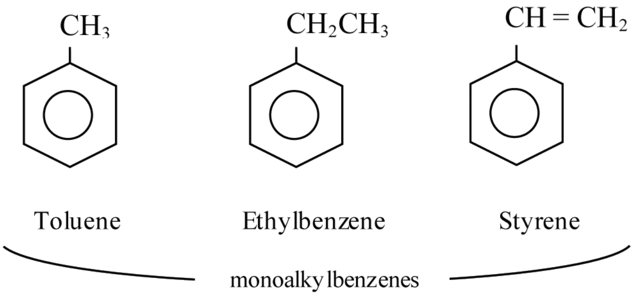


Figure 4
Derivatives of benzene

Disubstituted benzenes can exist as three different isomers. For example, xylene has three different isomers (Figure 5). The substituents location is denoted by a prefix: ortho (o-) , meta (m-) or para (p-). When the substituents are different, they appear in the name in alphabetic order. Benzene ring could be also a substituent group – C_6H_5 called phenyl.

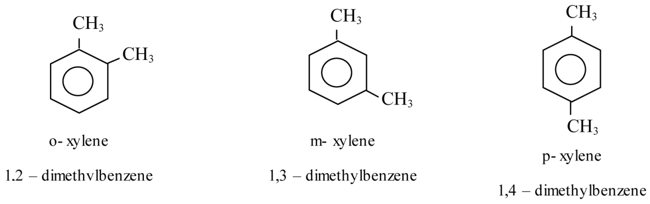


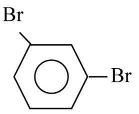
Figure 5
Xylene isomer

Problem 2. Write the structural formula of each of the following aromatic compounds or name them according to the IUPAC nomenclature.

a) 4-chlorotoluene ....

b) 2-phenylbutane ....

c)



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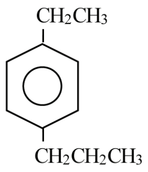
d)

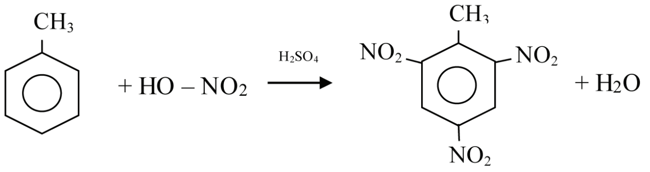


....

e) 1-chloro-2-phenylbutane ....

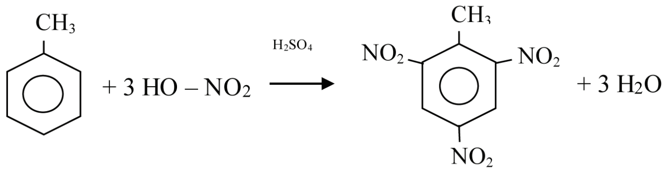
Problem 3. Two of the following equations represents correctly, the chemical reactions used to produce TNT (trinitrotoluene) and benzoic acid from toluene. Which are they?

a)



$$b)\ C_6H_5CH_3 \xrightarrow{\overset{(O)}{KMnO_4}} C_6H_5COOH$$

c)



$$d)\ C_6H_5CH_3 \xrightarrow{\overset{(O)}{KMnO_4}} C_6H_5CHO$$

Problem 4. Polystyrene is a polymer which has wide application and contains a few thousand monomers.

a) Write the chemical equation for styrene's polymerization (see Alkenes if necessary).

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b) Create a short presentation about polystyrene's applications and share with the class. Comment together the ways for environmental protection.

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Key terms

- aromatic compounds
- benzene
- Kekule's formula
- benzene derivatives
- substitution reactions
- substituents
- alkyl benzene
- carcinogen

22 Natural sources of hydrocarbons

An abundant supply of energy that was originally generated by the sun is provided now by woody plants, coal, petroleum, and natural gas. Plants store energy through photosynthesis, which can be used when plants are burned or, more frequently, their decay products that have been turned into fossil fuels.

Coal

Figure 1
Bituminous coal

Coal was created from plant remains that were buried, exposed to pressure and heat over an extended period of time. Coal "matures" through different stages and each stage brings a higher amount of carbon. The energy that can be released during its combustion increases as the carbon content in coal increases. Coal, especially those rich in sulphur, are big air pollutants. That's why chemists are constantly looking for innovative ways to use coal as an energy resource. One option is to produce a gaseous fuel. Large molecule-containing substances like coal typically have high boiling points and are either solids or thick liquids. That's why coal must be broken down in a process known as coal gasification (Figure 2) in order to be transformed from a solid to a gas. To accomplish this, coal is heated to a high temperature while being treated with steam and oxygen in order to break numerous carbon-carbon bonds. The final products are methane and synthetic gas. They can react with oxygen and release a great amount of heat as a result of their combustion. That makes them an exellent fuel.

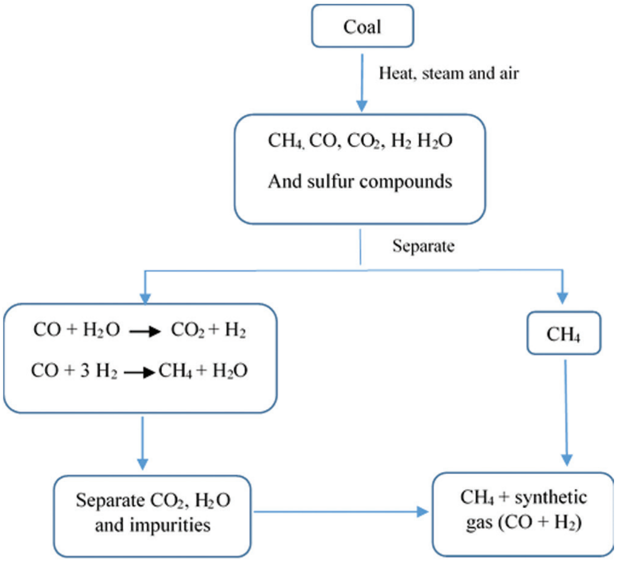


Figure 2
Coal gasification

Natural sources of hydrocarbons

22

Petroleum

It is composed of saturated and unsaturated hydrocarbons and aromatic hydrocarbons and their derivatives. In order to be used as different fuels, petroleum has to be refined into fractions through a process called fraction distillation. Each fraction contains mixture of different hydrocarbons that are valuable because of their properties. See Table 1. The separation of petroleum components is a physical process but chemical reactions are also involved.

Fraction	Number of carbon atoms	Uses
Gas	$C_1 – C_4$	Cooking gas
Petroleum ether	$C_4 – C_{10}$	Solvent
Gasoline	$C_6 – C_{12}$	Motor fuel
Kerosene	$C_{11} – C_{16}$	Rocket and air plane fuel
Fuel oil	$C_{14} – C_{18}$	Domestic heating
Asphalt	$>C_{50}$	Paving, roofing
Lubricating oil	$C_{15} – C_{24}$	Lubricants for automobiles and machines

Table 1
Fractions of petroleum

Another way to produce smaller molecules is by cracking processes. There are two types of cracking processes – at high temperature (pyrolysis, thermal cracking) and at low temperature using catalyst (catalytic cracking).

Catalytic reforming is also used as a refining method. Here, alkanes and cycloalkanes are converted into aromatic compounds in order to improve the octane number of gasoline. The octane number is a metric used to describe how well a gasoline can sustain compression in an internal combustion engine without igniting. Gasoline is the best known component of petroleum and it is a mixture of hexane, octane and their isomers. The octane number scale is used to rate the fuel's burning efficiency. An excellent gasoline with an octane rating of 100 is 2,2,4-trimethylpentane. Poor gasoline, as heptane, has an octane number of 0. These chemicals combined yield octane number 90. Hydrocarbons with an octane number greater than 100 burn more effectively than 2,2,4-trimethylpentane. As molecular weight increases, octane numbers decrease. Increased branching raises the octane number for isomeric molecules.

Project. Alternative fuels

Choose a topic and make a poster or presentation about alternative fuels.

– Hydrogen’s potential as a fuel
– Oil shale as an energy source
– Is it possible for ethanol to replace gasoline?

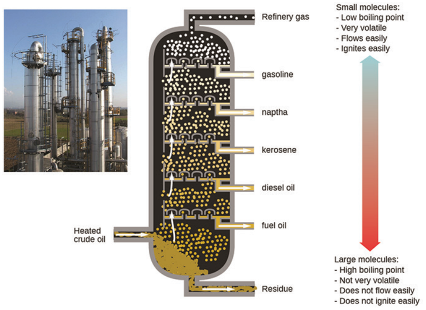
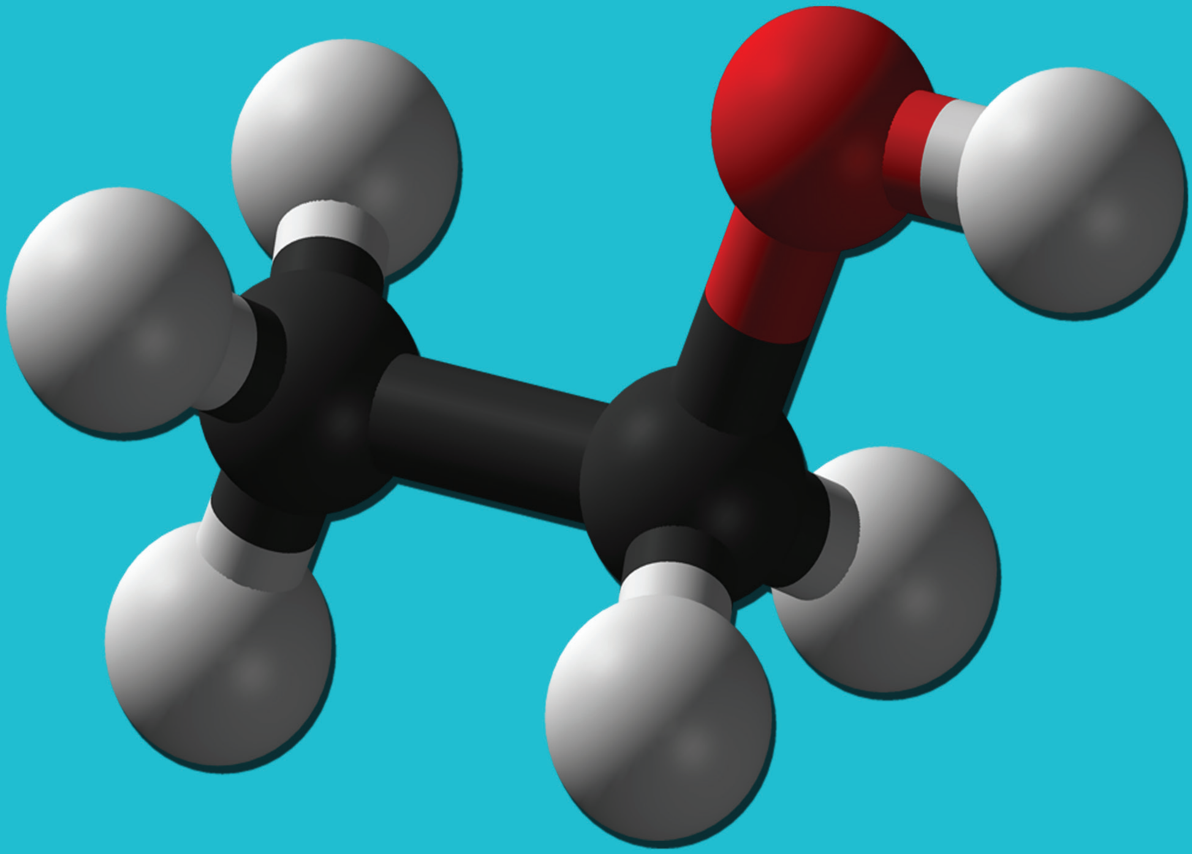


Figure 3
Fractionating column

Figure 4
Fuel dispenser

Part VI

Derivatives of hydrocarbons



23

Alcohols and phenols

Hydrocarbons derivatives – introduction

Except hydrogen and carbon atoms, organic compounds in general contain also other atoms such as halogens, oxygen, nitrogen, sulfur etc. When one or more hydrogen atoms are replaced with atoms or group of atoms called functional groups, hydrocarbon derivatives are formed (Figure 1). The functional group determines the reactivity and the properties of the organic molecules.

CH_3-H	CH_3OH	CH_3-CH_2-H	CH_3-CH_2-Cl
methane	methanol	ethane	chloroethane

Figure 1

Alcohols – homologous series, nomenclature and classification

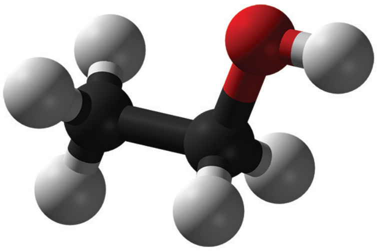


Figure 2
Ethanol

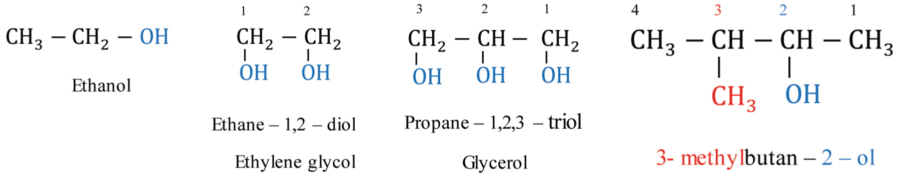
Alcohols are derivatives of hydrocarbons in which one or more hydrogen atoms are replaced by a hydroxyl (- OH) group. Their general formula is $C_nH_{2n+1}OH$.

Name	Structural formula
Methanol	CH_3OH
Ethanol	CH_3CH_2OH
1 – propanol	$CH_3CH_2\ CH_2OH$
2 – propanol	$CH_3CH\,(OH)\ CH_3$
alcohol	$C_nH_{2n+1}OH$

Table 1

Figure 2.1
Ethanol burning flame

The alcohols names are formed as the suffix –e from the corresponding hydrocarbon is replaced with the suffix – ol. For alcohols with more than three carbon atoms the IUPAC nomenclature for organic compounds applies (Figure 3).



CH_3-CH_2-OH Ethanol

$\underset{OH}{\overset{1}{CH_2}}-\underset{OH}{\overset{2}{CH_2}}$ Ethane – 1,2 – diol
Ethylene glycol

$\underset{OH}{\overset{3}{CH_2}}-\underset{OH}{\overset{2}{CH}}-\underset{OH}{\overset{1}{CH_2}}$ Propane – 1,2,3 – triol
Glycerol

$\overset{4}{CH_3}-\underset{CH_3}{\overset{3}{CH}}-\underset{OH}{\overset{2}{CH}}-\overset{1}{CH_3}$ 3- methylbutan – 2 – ol

Figure 3

Alcohols can be classified depending on the type of the carbon atom (primary, secondary, etc.) to which the hydroxyl group is attached (Figure 4).

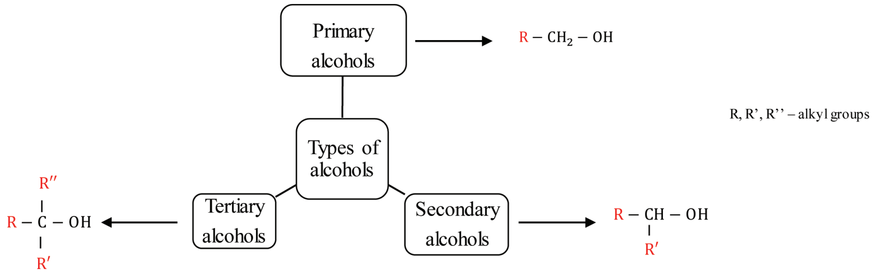
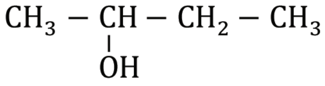
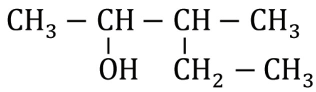


Figure 4

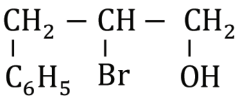
Problem 1. For each of the following compounds write the systematic name or the condensed formula and classify them as primary, secondary or tertiary alcohols.

a) 
$CH_3-\underset{\overset{|}{OH}}{CH}-CH_2-CH_3$ ....

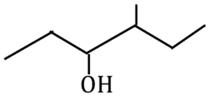
b) 
$CH_3-\underset{\overset{|}{OH}}{CH}-\underset{\overset{|}{CH_2-CH_3}}{CH}-CH_3$ ....

c) 2,3 – dimethylpentan – 2 ol ....

d) 2,2 – dimethylbutan – 1 – ol ....

e) 
$\underset{\overset{|}{C_6H_5}}{CH_2}-\underset{\overset{|}{Br}}{CH}-\underset{\overset{|}{OH}}{CH_2}$ ....

f) 3 – ethyl – 3 pentanol

g) 

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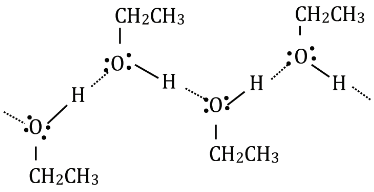


Figure 5

Physical properties

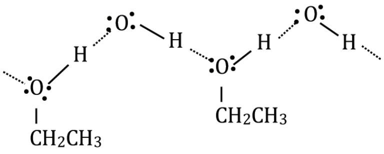


Figure 6

Most of the alcohols are liquids with high boiling points than expected because intermolecular bonds occur. (Figure 5) Alcohols have great solubility in water because water molecule and alcohol's molecules form hydrogen bonds. Alcohols' solubility decreases as the number of carbon atoms in the molecules increases. (Figure 6) When the hydroxyl groups

are more than one they can participate in the formation of more hydrogen bonds. Therefore, alcohols with more than one – OH group have higher boiling points and are more soluble in water than alcohols with only one – OH group.
Methanol and ethanol are the simplest alcohols but with great commercial value. Methanol (methyl alcohol) is a colorless liquid with very characteristic alcohol odor and taste. This alcohol is poisonous and small amounts of it may cause blindness and death. Methanol is called wood alcohol because it was obtained from wood in the absence of air and in the presence of heat. Now, for industrial purposes, methanol is produced by hydrogenation of carbon oxide.

$$CO + 2H_2 \xrightarrow[ZnO/Cr_2O_3]{400^0C} CH_3OH$$

Ethanol known as ethyl alcohol or just alcohol is main ingredient in many alcoholic drinks like beer, wine, vodka, whiskey, etc. It is a colorless liquid with characteristic odor, soluble in water in any proportion. Ethanol is produced mainly in two ways – alcoholic fermentation and hydration of ethene.

Chemical properties

Alcohols have amphoteric properties. The basic properties are defined by oxygen's lone pair of electrons and acidic properties occurs because of the polar – OH bond.

– Interaction with sodium:

$$CH_3-CH_2-O-H + Na \longrightarrow CH_3-CH_2-O-Na + H_2$$

Sodium ethoxide

– Esterification

$$CH_3-CH_2-\boxed{OH\ +\ H}O-NO_2 \xrightleftharpoons{H_2SO_4} CH_3-CH_2-O-NO_2 + H-OH$$

Ethyl nitrate (ester)

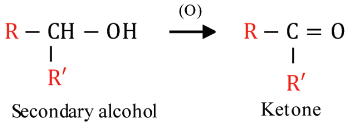
– Combustion

$$CH_3CH_2OH + 3\,O_2 \longrightarrow 2\,CO_2 + 3\,H_2O + Q$$

– Oxidation

$R-CH_2-OH \xrightarrow{(O)} R-CHO \xrightarrow{(O)} R-COOH$

Primary alcohol Aldehyde Carboxylic acid



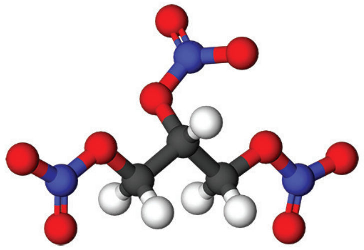
$R-\underset{\displaystyle R'}{\underset{|}{CH}}-OH \xrightarrow{(O)} R-\underset{\displaystyle R'}{\underset{|}{C}}=O$

Secondary alcohol Ketone

– Dehydration $CH_3CH_2OH \xrightarrow[H_2SO_4]{t^0\ 160-180^0} CH_2{=}CH_2 + H_2O$ intramolecular dehydration

$2\ CH_3CH_2OH \xrightarrow[H_2SO_4]{t^0 < 140^0} CH_3-CH_2-O-CH_2-CH_3 + H_2O$ intermolecular dehydration

Diethyl ether



Problem 2. Glycerin reacts with nitric acid in the presence of sulfuric acid. The product is a compound known as a medicine used to relax the blood vessels, which increases the oxygen supply of the heart. Mixed with sorbents and stabilizers it forms dynamite.

a) Write the chemical equation of the process

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Figure 7
Nitrogylcerin

b) Name the product using the IUPAC nomenclature and the process

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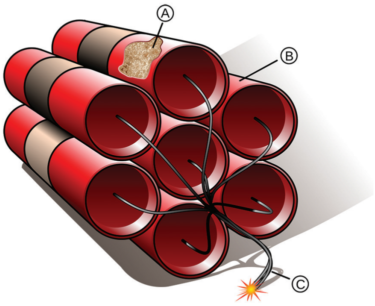

Figure 8
Dynamite

Problem 3. Which two of the following compounds ethene, chloroethane, propene, propane, water, hydrogen you would use to synthesize propan-2-ol?

a) Write the chemical equation

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b) Write the equation of the oxidation of propane-2-ol

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c) What is the name of the compound formed when propane-2-ol is heated at temperature higher than 140^{0}C?

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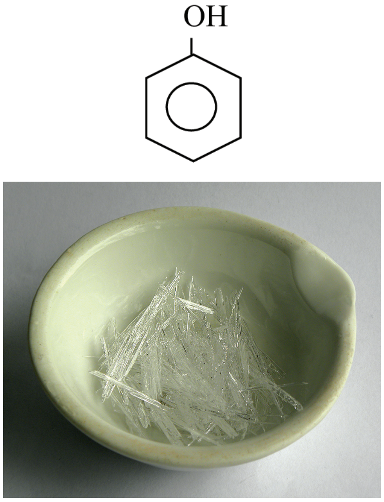


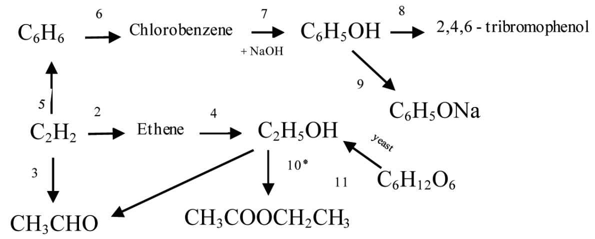
Figure 9
Phenol

Phenols

The simplest phenol is called benzenol (phenol) (Figure 9). It is a colorless solid with characteristic odor, slightly soluble in water at room temperature. The solubility of phenol increases as the temperature increases. Phenol and its vapors irritate the eyes, the skin and the respiratory tract and they are poisonous.
Their chemical properties are defined by the hydroxyl group (– OH) and the benzene ring. Phenols dissociates in water into positive hydrogen ions, which determines their acidic properties. Phenols react with bases forming salts called phenoxides. The benzene ring defines aromatic properties and all the reactions characteristic for benzene are present.

Key terms

- hydrocarbon derivatives
- hydroxyl group
- alcohol
- primary alcohol
- secondary alcohol
- tertiary alcohol
- alkoxides
- ester
- phenols
- phenoxides



Problem 4. Write down all chemical equations (1 – 11) of the reactions in the figure. Name each compound according to the IUPAC nomenclature and write its structural formula.

1. ....

2. ....

3. ....

4. ....

5. ....

6. ....

7. ....

8. ……………………………………………………………………

9. ……………………………………………………………………

10. ……………………………………………………………………

11. ……………………………………………………………………

Problem 5. Draw the structural formulas of all possible chain and positional isomers of an alcohol with molecular formula $C_5H_{12}O$.

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Problem 6. Which alcohol will have greater solubility in water: propanol or hexanol? Why? Try to draw the hydrogen bonds formation between the propanol and the water molecules.

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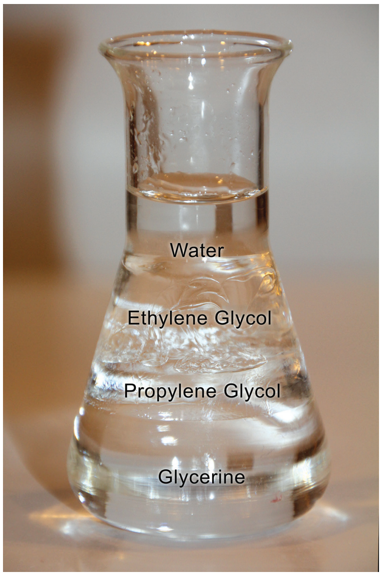


Figure 10
Layers of glycerine,
propylene glycol,
ethylene glycol
and water

More……

A breath analyzer test for alcohol is used for detecting ethanol in the breath of drivers. It's an oxidizing reaction between potassium dichromate which is a yellow-colored compound and alcohols. When the driver breathes into a tube, an electronic device detects the intensity of the yellow color, which diminishes if there is alcohol. The amount that is found in the breath is equal to the amount of the alcohol in the blood.
A test reagent for vicinal hydroxyl groups is $Cu(OH)_2$ which is blue precipitate. The product of the reaction is soluble compound with intensive dark blue color.
A test reagent for the presence of phenol is FeCl3. The solution has brown color which turns into a very beautiful and characteristic violet color if phenol is present in the sample.

24

Aldehydes and ketones

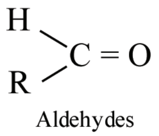


Figure 1

Aldehydes and ketones contain a carbonyl group $>C = O$. It is the functional group of these compounds and consists of carbon atom bonded to oxygen atom with double covalent bond. In aldehydes, the carbonyl carbon atom is always bonded to at least one hydrogen atom. In ketones, the carbon atom is bonded to two other carbon atoms.

Homologues, isomerism and nomenclature

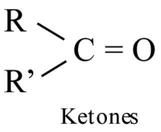
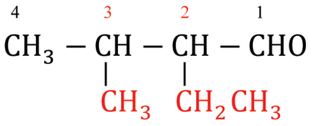


Figure 2

In Table 1 the homologous series of aldehydes and ketones is presented. For aldehydes the final -e of the alkane’s name is replaced with a suffix – al and for ketones the suffix is – one. Aldehydes have structural isomerism. Ketones have both structural and positional isomerism.

Formula (CHO)	Names	Formula (C=O)	Names
HCHO	Methanal	–	–
CH_3CHO	Ethanal	–	–
CH_3CH_2CHO	Propanal	CH_3COCH_3	Propanone dimethyl ketone
$CH_3CH_2CH_2CHO$	Butanal	$CH_3CH_2COCH_3$	Butanone ethyl methyl ketone
$C_nH_{2n+1}CHO$	Aldehyde	$C_nH_{2n+1}COC_nH_{2n+1}$	Ketone

Table 1. Homologous series of aldehydes and ketones



$$\overset{4}{CH_3} - \underset{CH_3}{\overset{3}{CH}} - \underset{CH_2CH_3}{\overset{2}{CH}} - \overset{1}{CHO}$$

2 – ethyl – 3 – methylbutanal

Figure 3

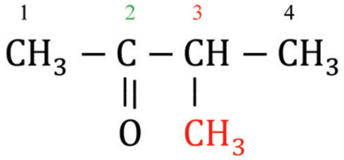
IUPAC set rules for naming aldehydes and ketones.

For aldehydes rules are as it follows:
1. The main chain is the longest and the one that includes the aldehyde carbon atom.

2. The numbering starts from the aldehyde’s carbon atom. This carbon atom is always first and that’s why the number 1 showing its position is omitted in the name.

3. The branches type and location are added to the name with the corresponding numbers showing their positions and in alphabetical order.

For ketones rules are as it follows:
1. The main chain is the longest and the one that includes the ketone carbon atom.
2. The numbering starts from the end of the carbon chain so that the ketone carbon atom receives the lowest number. The number showing its position is added as prefix in the name.
3. The branches type and location are added to the name with the corresponding numbers showing their positions and in alphabetical order.

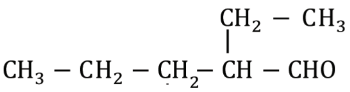


$$\overset{1}{CH_3} - \underset{\underset{\displaystyle O}{||}}{\overset{2}{C}} - \underset{\underset{\displaystyle CH_3}{|}}{\overset{3}{C}H} - \overset{4}{CH_3}$$

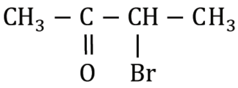
3 – methylbutan – 2 – one

Figure 4

Problem 1. Write the systematic names of the following compounds or their structural formula

a)  ....

$$CH_3 - CH_2 - CH_2 - \overset{\overset{\displaystyle CH_2 - CH_3}{|}}{C}H - CHO$$

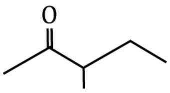
b)  ....

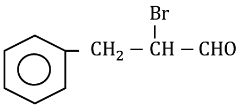
$$CH_3 - \underset{\underset{\displaystyle O}{||}}{C} - \underset{\underset{\displaystyle Br}{|}}{C}H - CH_3$$

c) 2 – methylbutanal ....

d) 2,3 – dichloropentanal ....

e) 3,4 – dimethylpentan – 2 – one ....

f)  ....

g) 

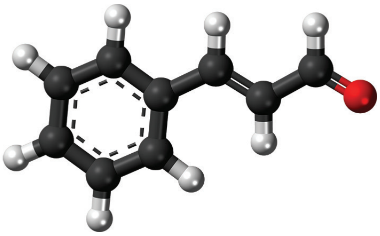


Figure 5
Cinnamaldehyde

Problem 2. Draw the structural formulas of all possible skeletal and positional isomers of

a) an aldehyde with molecular formula C_4H_9CHO
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....
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Figure 6
Essential oil

b) a ketone with molecular formula $C_5H_{10}O$

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Physical and chemical properties

Figure 7
Ground Cinnamon Powder and a Cinnamon Stick

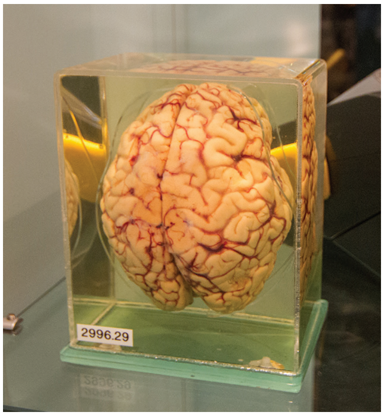


Figure 8
Human brain preserved in formaldehyd

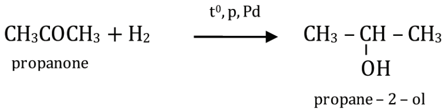
The simplest representatives of the aldehydes are methanal (formaldehyde) and ethanal (acetaldehyde). They are gases at room temperature. Aldehydes contain up to eleven carbon atoms are liquids and aldehydes with more than 12 carbon atoms – solids. The first representative in the ketones' homologous series is acetone. It is a colorless liquid with sharp odor and the most used solvent in the industry.

Aldehydes and ketones have higher boiling points than alkanes but lower than alcohols. The reason is the carbonyl group can form hydrogen bonds with the water molecules. Their solubility in water decreases as the number of carbon atoms increases. Formaldehyde, acetaldehyde and acetone are soluble in all proportions in water.

Aldehydes have higher chemical reactivity than ketones but both undergo addition reactions because of the carbon – oxygen polar double bond.

– Hydrogenation $$\underset{\text{methanal}}{HCHO + H_2} \xrightarrow{t^0,\,p,\,Pd} \underset{\text{methanol}}{CH_3 - OH}$$

– Oxidation_



$$\underset{\text{propanone}}{CH_3COCH_3 + H_2} \xrightarrow{t^0,\,p,\,Pd} \underset{\text{propane} - 2 - \text{ol}}{CH_3 - \underset{OH}{\underset{|}{CH}} - CH_3}$$

The reaction between aldehydes and a solution of Ag_2O dissolved in aqueous ammonia (Tollens' reagent) is called silver mirror. In this reaction, the aldehyde is oxidized and the metallic silver produced coats the walls of the test tube like a mirror. Another oxidizing agent of the aldehyde group is the Fehling's solution ($Cu(OH)_2$). The blue-colored solution of $Cu(OH)_2$ turns into brick – red because of the presence of Cu_2O. Tollens' reagent and Fehling's solution are mild oxidizing agents and these reactions are test reactions for the presence of aldehyde group.

$$\underset{\text{methanal}}{HCHO} + Cu(OH)_2 \xrightarrow{t^0} \underset{\text{formic acid}}{HCOOH} + Cu_2O + 2\,H_2O$$

Ketones are oxidized under special conditions with breakage of the carbon – carbon bond and formation of two carboxylic acids.

$$\begin{tikzcd} \underset{\text{propanone}}{CH_3-CO-CH_3} \arrow[r, "t^0, K_2Cr_2O_7/H_2SO_4"] & \underset{\text{acetic acid}}{CH_3-COOH} + \overset{\text{formic acid}}{HCOOH} \arrow[d, "(O)"] \\ & CO_2 + H_2O \end{tikzcd}$$

Figure 9
Nail polish remover

Problem 3. The compound **A** with molecular formula C_3H_6 is an odorless and colorless gas. Test reagent for **A** is $KMnO_4$ solution because when it is added to the solution its purple color fades away. **A** also reacts with water producing **B** and with chlorine producing **C**. Undergoing oxidation, **B** turns into **D**. Compound **D** can be oxidized under special conditions and produces two acids **E** and **F** which have molecular formulas CH_2O_2 and $C_2H_4O_2$.

Figure 10
Sample of Acetone

a) Which are the compounds **A, B, C, D, E** and **F?**

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b) Write the chemical equations of the reactions described in the text.

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24

Aldehydes and ketones

Key terms

- carbonyl group
- ketones
- aldehydes
- silver mirror reaction
- Tollens' reagent
- Fehling's solution

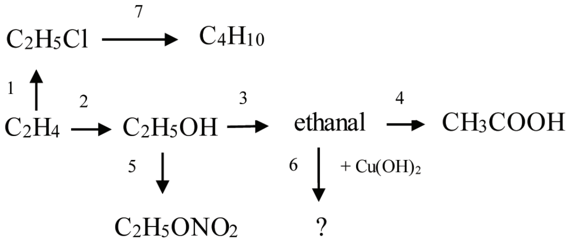
Problem 4. Word search: Find the words from the list in the table below

Word list

1. Aldehyde 2. Tollens' reagent 3. Ketone 4. Hydrogenation 5. Combustion 6. Carbonyl group 7. Acetone 8. Methanal 9. Formalin 10. Solvent

a	g	y	n	l	e	o	a	p	b	f	e	g	s	q	r
t	o	l	e	n	s	r	e	a	g	e	n	t	e	f	o
b	l	h	l	t	a	q	e	x	z	x	c	r	h	m	c
j	a	l	g	v	o	k	c	n	m	e	t	g	y	c	a
t	n	a	l	d	e	h	y	d	e	t	g	h	d	o	p
s	a	d	f	t	j	k	m	c	o	p	v	d	r	m	e
f	h	l	o	c	v	y	m	l	d	g	w	q	o	b	r
m	t	n	c	t	f	j	t	a	q	s	n	p	g	u	v
r	e	h	v	n	k	p	f	w	r	m	c	f	e	s	o
t	m	x	z	e	n	o	t	e	c	a	v	m	n	t	u
a	l	d	e	v	r	h	y	d	r	o	h	v	a	i	n
d	v	t	o	l	v	e	s	f	t	n	m	p	t	o	v
r	t	o	v	o	o	y	f	o	r	m	a	l	i	n	e
t	b	o	p	s	x	v	r	t	u	s	b	n	o	m	p
a	w	v	n	m	l	t	e	r	q	k	l	p	n	l	c
a	s	d	f	g	h	j	k	l	p	o	i	u	y	t	r
e	r	c	a	r	b	o	n	y	l	g	r	o	u	p	i

Problem 5. Write down all chemical equations (1 – 7) for the reactions given in the figure. Name the compounds according to the IUPAC nomenclature.



1. ....
2. ....
3. ....
4. ....
5. ....
6. ....
7. ....

Carboxylic acids

25

Carboxylic acids are organic acids which contain a carboxyl group – COOH. The name of this functional group is carboxyl because it consists of a **carbo**nyl group and a hydro**xyl** group.

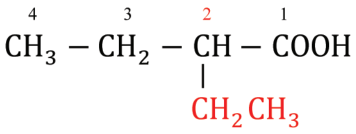
Homologous series, isomerism and nomenclature

The structural formulas and the systematic and common names of the first four unbranched carboxylic acids are given in Table 1.

Structural formula	**IUPAC name**
HCOOH	Methanoic acid (formic acid)
CH_3COOH	Ethanoic acid (acetic acid)
$CH_3CH_2\,COOH$	Propanoic acid
$CH_3CH_2CH_2COOH$	Butanoic acid
$C_nH_{2n+1}COOH$	Carboxylic acid

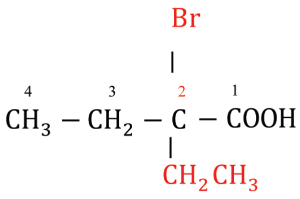
Table 1

The names of the branched carboxylic acids are formed using the IUPAC nomenclature, as well. The final -e in the corresponding alkane's name is replaced with -oic acid in the name of the carboxylic acid. The numbering of the chain starts from the carboxylic carbon atom and the number 1 doesn't have to be specified in the name. The branches are listed in alphabetic order with numbers which show their place in the main chain. Typical for carboxylic acids is structural isomerism.



$$\overset{4}{CH_3}-\overset{3}{CH_2}-\underset{\displaystyle CH_2CH_3}{\overset{2}{CH}}-\overset{1}{COOH}$$

2 – ethylbutanoic acid

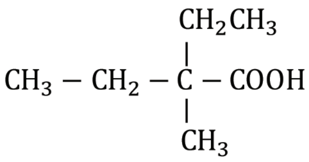


$$\overset{4}{CH_3}-\overset{3}{CH_2}-\underset{\displaystyle CH_2CH_3}{\overset{\displaystyle Br}{\overset{2}{C}}}-\overset{1}{COOH}$$

2 – bromo – 2 – ethylbutanoic acid

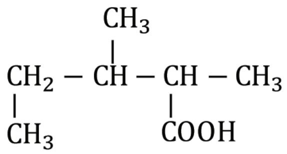
Problem 1. Write the systematic names of the following compounds or their structural formula

a)



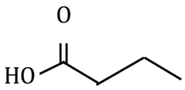
$$CH_3-CH_2-\underset{\displaystyle CH_3}{\overset{\displaystyle CH_2CH_3}{C}}-COOH$$

....

b)

$\underset{CH_3}{\underset{|}{CH_2}} - \overset{CH_3}{\overset{|}{CH}} - \underset{COOH}{\underset{|}{CH}} - CH_3$ ....

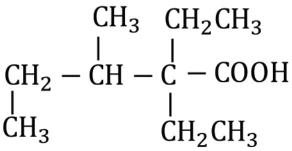
c) 4 – chloro – 3 – ethylpentanoic acid ....

d) HOOC - COOH* ....

e)


....

f) 2 – chloro – 4,4 – dimethylhexanoic acid ....

g)

$\underset{CH_3}{\underset{|}{CH_2}} - \overset{CH_3}{\overset{|}{CH}} - \overset{CH_2CH_3}{\overset{|}{\underset{CH_2CH_3}{\underset{|}{C}}}} - COOH$ ....

Physical properties

Carboxylic acids with lower molecular weight are liquids with an unpleasant odor, soluble in water. The reason for their good solubility is the hydrogen bonds formation between water and the carboxyl group. The boiling points of carboxylic acids are high because hydrogen bonds between two carboxylic acids can form and hold them as dimers. (Figure 1)

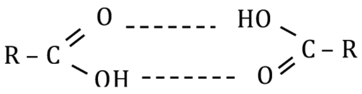


Figure 1

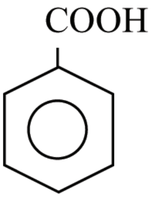


Figure 2

Formic acid HCOOH is the simplest carboxylic acid. The name comes from Latin (*formica* for ant) and it refers to its origin. The acid was isolated for a first time by a distillation of ant bodies. It is a colorless liquid with a characteristic odor.

Acetic acid CH_3COOH constitutes vinegar and it is the most widely used carboxylic acid. It is a colorless liquid with strong unpleasant odor often used as a solvent. Anhydrous acetic acid is called glacial acetic acid and it causes painful burns.

Benzoic acid (Figure 3) is the simplest aromatic carboxylic acid. It is solid, colorless and soluble in water. It is used as food preservative E210.

Carboxylic acids

25

Chemical properties

In water solution carboxylic acids act as weak acids and dissociate reversibly into a negative carboxylate ion and a positive hydrogen ion.

$$CH_3COOH \rightleftarrows CH_3COO^- + H^+$$

Similar to inorganic acids, carboxylic acids normally react with active metals, basic oxides and hydroxides. Carboxylic acids react also with alcohols producing esters. The process is called esterification.

$$CH_3COOH + HOCH_2CH_3 \overset{H_2SO_4}{\leftrightarrows} \underset{\text{Ethyl acetate}}{CH_3COOCH_2CH_3} + H_2O$$

Fruits have their typical odor due to esters like ethyl ethanoate which is present in pineapples, 3 – methylbutyl ethanoate present in apples and bananas, octyl ethanoate in oranges etc. Other typical reactions are substitution reactions in the side chain and combustion. The main difference between organic and inorganic acids is that organic acids undergo combustion.

Problem 2. Write and balance the equations of the following reactions. Name the products using the IUPAC nomenclature.

a) acetic acid and $Ca(OH)_2$

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b) propanoic acid and potassium

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c) formic acid's combustion

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Figure 3
Baking soda
and vinegar

Figure 4
Chilli and vinegar
bottles

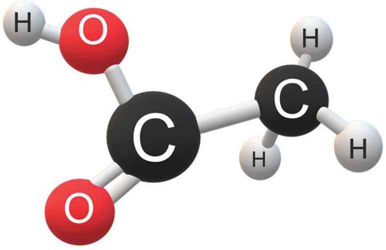

Figure 5
Vinegar acetic acid

Key terms

- Carboxylic acids
- carboxyl group
- esters
- dimer

Problem 3. Substitution reactions are typical for benzoic acid – halogenation, nitration etc. The carboxylic group orientates the new substitutes to meta place in the benzene's ring. It can also react with salts.

a) Write the equation of the nitration of benzoic acid in the presence of H_2SO_4 and heat

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....

b) Benzoic acid reacts with sodium carbonate. Write and balance the equation.

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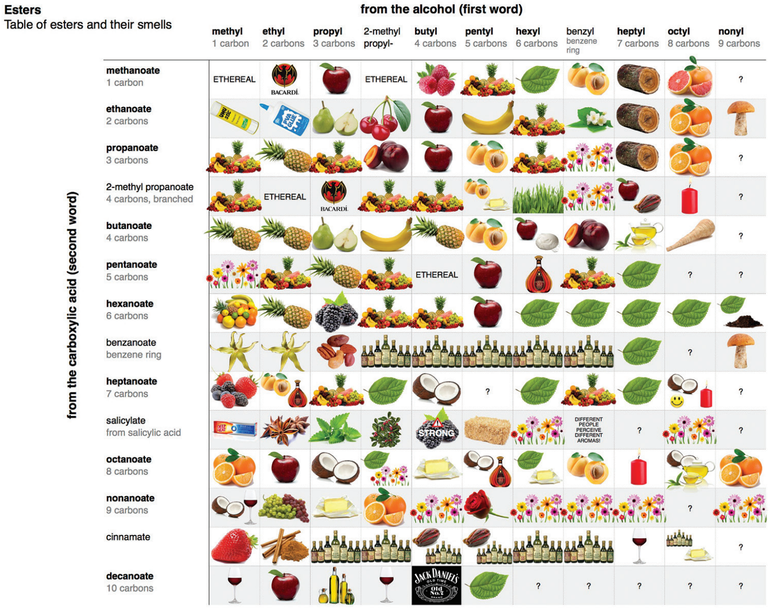

Figure 6

Problem 4. Write the condensed structural formulas of the acids and alcohols that produce the following esters in the process esterification. Use Figure 6 to define their flavors.

a) Octyl acetate

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b) Ethyl methanoate

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c) Pentyl acetate

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d) Use Figure 6 and write the structural formula of the ester which causes your favorite smell or taste

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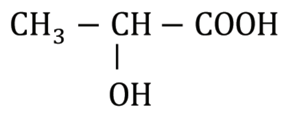
Hydroxy carboxylic acids

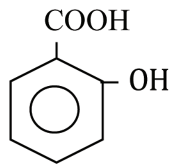
This family of acids contains two functional groups – carboxylic group and hydroxyl group. The most important representatives of the hydroxyl carboxylic acids are lactic acid and salicylic acid. (Figure 8)



$$\underset{\displaystyle OH}{CH_3 - \underset{|}{CH} - COOH}$$

2 – hydroxypropanoic acid

Figure 7
Lactic acid



2 – hydroxybenzoic acid

Figure 8
Salicylic acid

Problem 5.* Acetylsalicylic acid or aspirin (Figure 9) is an ester of salicylic acid and acetic anhydride $(CH_3CO)_2O$ which is used as a pain killer and antipyretic. Phenyl salicylate or salol (Figure 10) is an ester of salicylic acid which is used as sunscreen or antiseptic. Write the structural formulas of the reactants required to produce these compounds. What are the differences between the two reactions?

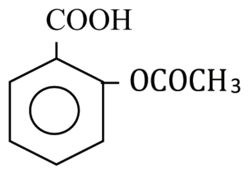


Figure 9
Acetylsalicylic acid
(aspirin

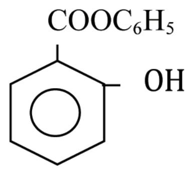


Figure 10
Salol

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Part VII
Biochemistry

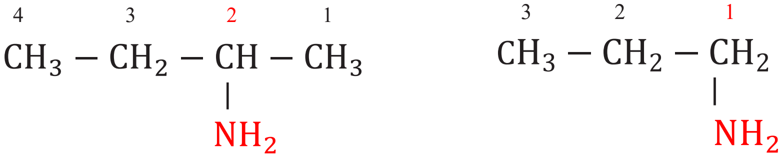
Amines and α-amino acids

26

Amines are derivatives of ammonia in which one or more hydrogen atoms are replaced by alkyl groups. Depending on how many hydrogen atoms are being replaced, the amines can be primary, secondary or tertiary.

Nomenclature

The IUPAC system for naming amines is similar to that of alcohols. For primary amines, the name of the alkane attached to the nitrogen atom is used as a prefix. The – NH_2 group is called amino group and the suffix amine and it is added to the name of the alkane. A number indicating the amino group position is placed between them (Figure 1).



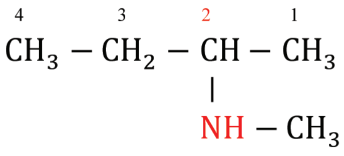
$\overset{4}{CH_3}-\overset{3}{CH_2}-\underset{NH_2}{\underset{|}{\overset{2}{CH}}}-\overset{1}{CH_3}$ $\qquad$ $\overset{3}{CH_3}-\overset{2}{CH_2}-\underset{NH_2}{\underset{|}{\overset{1}{CH_2}}}$

butane-2-amine

Propane-1-amine

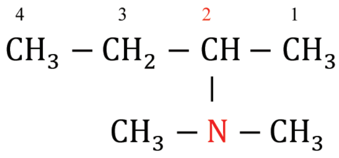
Figure 1

For secondary and tertiary amines, the largest carbon chain is the parent chain and the alkyl groups are added with prefix N or N, N to show the alkyl group is attached to the nitrogen atom and not to the hydrocarbon chain. For example,



$\overset{4}{CH_3}-\overset{3}{CH_2}-\underset{NH-CH_3}{\underset{|}{\overset{2}{CH}}}-\overset{1}{CH_3}$

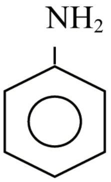
N-methylbutane-2-amine



$\overset{4}{CH_3}-\overset{3}{CH_2}-\underset{CH_3-N-CH_3}{\underset{|}{\overset{2}{CH}}}-\overset{1}{CH_3}$

N, N-dimethylbutane-2-amine

The simplest aromatic amine is aniline



26 Amines and α-amino acids

Problem 1. Provide the systematic names of the following compounds. Define them as primary, secondary or tertiary amines.

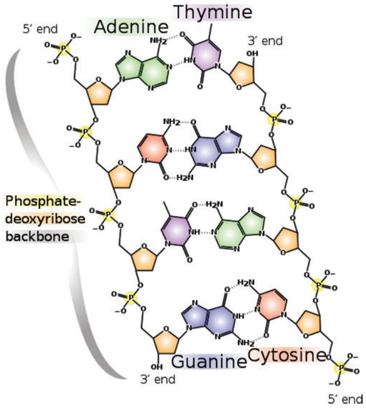
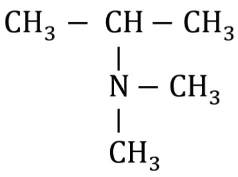
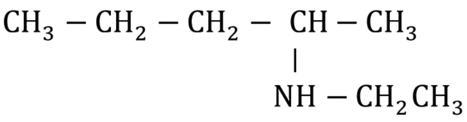


Figure 3
The DNA structure

a)


$$\begin{array}{lll} CH_3 - & CH & - CH_3 \\ & | & \\ & N - CH_3 & \\ & | & \\ & CH_3 & \end{array}$$

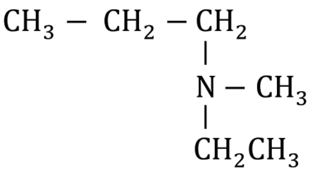
....

b)


$$\begin{array}{ll} CH_3 - CH_2 - CH_2 - & CH - CH_3 \\ & | \\ & NH - CH_2CH_3 \end{array}$$

....

c) $N(CH_3)_3$ ....

d)


$$\begin{array}{ll} CH_3 - CH_2 - & CH_2 \\ & | \\ & N - CH_3 \\ & | \\ & CH_2CH_3 \end{array}$$

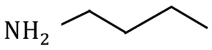
e)


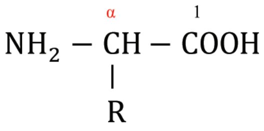
Figure 4
Bhola fish

Physical and chemical properties

Amines with a small number of carbon atoms have a fishy odor and are soluble in water. They have higher boiling points than alkanes with the same number of carbon atoms because of the hydrogen bonds they can form. Amines have weak basic chemical properties and easily reacts with strong acids forming ammonium salts.

Amino acids

The **amino acids** contain an amino group and a carboxylic group. α-amino acids are the building blocks of proteins. They have an amino group attached to the carbon atom next to the carboxylic carbon atom, which is called the α-carbon atom.



$$\begin{array}{ll} NH_2 - & \overset{\alpha}{CH} - \overset{1}{COOH} \\ & | \\ & R \end{array}$$

α-amino acids

Amines and α-amino acids 26

Physical and chemical properties

Amino acids are solids moderately soluble in water. The amino group justifies basic properties and the carboxylic group is responsible for acidic properties in the same molecule. That’s why amino acids have amphoteric properties. These functional groups react with each other and produce a salt with ionic structure called zwitterion (Figure 5).

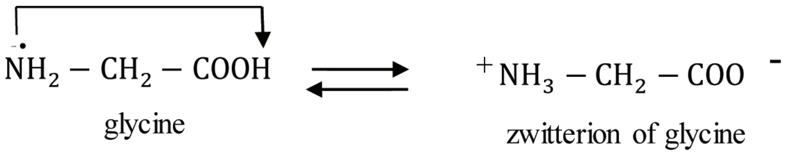


Figure 5 Producing zwitterion of glycine

Key terms

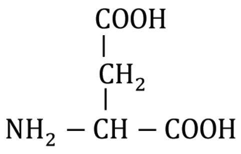
- amines
- α amino acids
- peptide bond
- peptides

Because of the carboxylic group, α-amino acids react with active metals, metal oxides and hydroxides and salts of weaker acids. The amino group is the reason they react with acids.
When two or more amino acids reacts with each other a peptide is formed. The bond that is formed is called peptide bond. Depending on the number of the amino acids, there are dipeptides, tripeptides etc. A peptide with less than 50 amino acids is called polypeptide. Their names are a combination of all the amino acids which constitute the molecule.

$$NH_2 - CH_2 - COOH + NH_2 - CH_2 - COOH \longrightarrow {}^+NH_3 - CH_2 - CO - NH - CH_2 - COO^- + H_2O$$

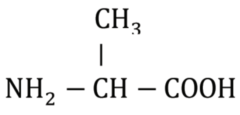
Glycylglycine
Gly - Gly

Problem 2.* Write all the possible tripeptides that could be formed from the amino acids GLY, ALA and ASP.



$$\begin{array}{c} COOH \\ | \\ CH_2 \\ | \\ NH_2 - CH - COOH \end{array}$$

Aspartic acid (ASP)



$$\begin{array}{c} CH_3 \\ | \\ NH_2 - CH - COOH \end{array}$$

Alanine (ALA)

$NH_2 - CH_2 - COOH$

Glycine (GLY)

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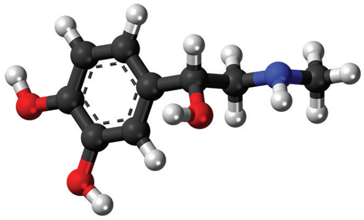

Figure 6
Adrenaline

Problem 3. Adrenaline or epinephrine (medication) is a hormone which is released when people feel fear or anxiety. Dopamine is a hormone which makes us more focus, gives us the ability to think, plan and to feel pleasure. Look at Figure 8, which are the functional groups you find? Which one is primary amine and which one is secondary amine?

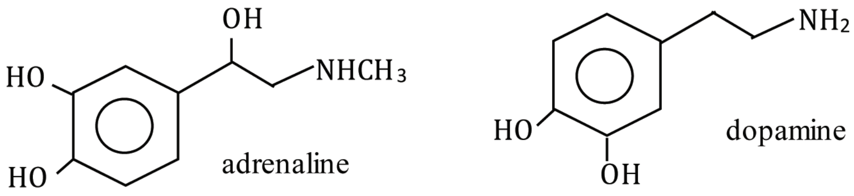

Figure 8
Structural formulas of adrenaline and dopamine

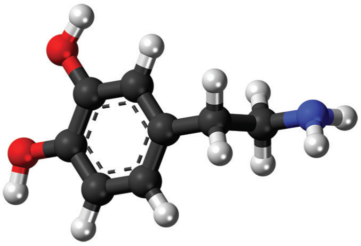

Figure 7
Dopamine

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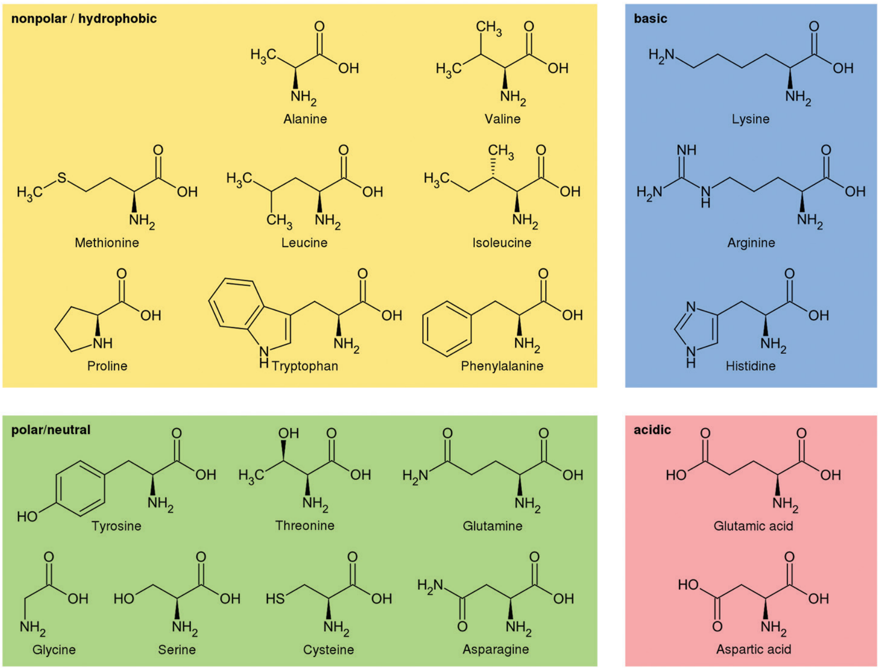


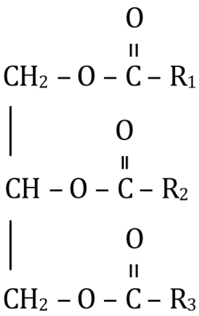
Figure 8
Proteinogenic amino acids

Fats, oils and soaps

27

Lipids are compounds soluble in non-polar organic solvents and insoluble in water. In human bodies, there are four types of lipids – fats, phospholipids, waxes and steroids. We often use fats as a synonym of lipids. The natural fats and oils are mixtures of esters of glycerol and long chained carboxylic acids called fatty acids. These esters are called triglycerides (triacylglicerols). Their structural formulas are shown in Figure xx where R_1 R_2 R_3 may be different or the same saturated or unsaturated acyl groups (part of the fatty acid). As we all know, fats are liquids and solids, depending on their origin. Vegetable fats are unsaturated oily liquids and animal fats are saturated and solid. (Figure 2) olive oil and butter)


Olive oil

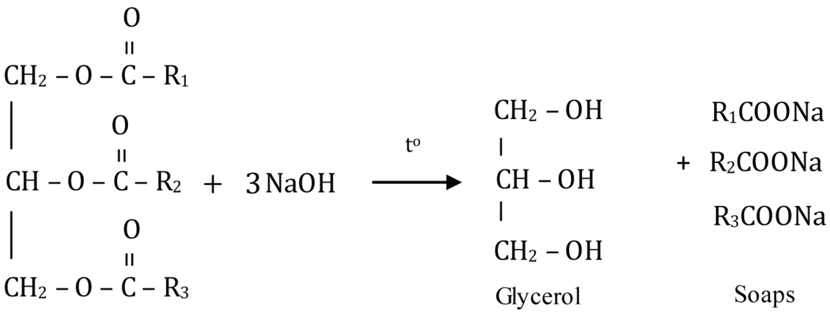


$$\begin{array}{l} CH_2-O-\overset{\overset{O}{\|}}{C}-R_1 \\ | \\ CH-O-\overset{\overset{O}{\|}}{C}-R_2 \\ | \\ CH_2-O-\overset{\overset{O}{\|}}{C}-R_3 \end{array}$$

Figure 1
Structural formula of triglyceride


Figure 2
Butter

When heated and treated with aqueous solution of sodium or potassium hydroxide, fats decompose and turn into sodium or potassium salts and glycerol. This process is called saponification. (Figure 3 Soaps are product of process saponification). Sodium soaps are solids and potassium soaps are liquids.



$$\begin{array}{l} CH_2-O-\overset{\overset{O}{\|}}{C}-R_1 \\ | \\ CH-O-\overset{\overset{O}{\|}}{C}-R_2 \\ | \\ CH_2-O-\overset{\overset{O}{\|}}{C}-R_3 \end{array} + 3NaOH \xrightarrow{t^o} \begin{array}{l} CH_2-OH \\ | \\ CH-OH \\ | \\ CH_2-OH \end{array} + \begin{array}{l} R_1COONa \\ R_2COONa \\ R_3COONa \end{array}$$


Figure 3
Soaps

We often say “My hands are dirty”, we grab a soap and wash them. But how soap removes the dirt from our hands? The so-called dirt is nonpolar and polar water molecules are not able to remove it. In order to wash them we need to add soap because soap molecules have long nonpolar tails. They have also polar heads. The polar head interacts with water while the nonpolar tail with the nonpolar dirt. The soap water actually contains groups of fatty – acid anions called micelles which carry away the dirt. But soap has some disadvantages too. Its cleaning efficiency could be reduced if the water is hard. Nowadays, industry produces molecules similar to soaps that do not form precipitates with hard water, called detergents. The most common detergents are alkylbenzene sulfonates (Figure 5).

Figure 4
Laundry detergents

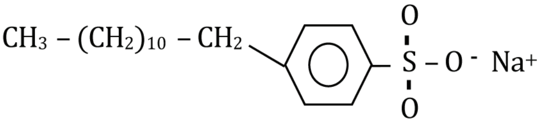


Figure 5
Sodium dodecylbenzenesulfonate

Project 1. Facial cleanser
Which is your favorite facial cleanser? What are you going to use to clean you face – micellar water or cream soap? Find information on the internet

1. How micellar water and soap work?
2. What are their ingredients?
3. Which one is better for face cleaning and why?

Project 2. Test it
Make a soap, laundry detergent and dish washing liquid solutions and test them with a universal indicator. Answer the following questions based on the results

a) Which one you would use for washing wool and cotton clothes?
b) Make a test if the water in your town affects the cleaning efficiency of the laundry detergent

Materials

1. soap, laundry detergent, dishwashing liquid
2. distilled water
3. tab water
4. universal indicator
5. four small jars and three small cups

Steps

Testing pH

1. pour 50 ml distilled water in three cups
2. label them
3. cut some soap and add it to the first cup, add 1 table spoon laundry detergent and 1 table spoon dishwashing liquid to the second and the third. Stir them up and test with the indicator

Testing cleaning efficiency

1. use four small jars and label them
2. in each one pour 100 ml tab water and add soap, laundry detergent and dishwashing liquid. The fourth jar is your control sample. Close the jars and shake them well.

Questions to think about

1. Before testing pH make a suggestion for pH values of each solution? Are they what you suggested?
2. Which one you will use for washing wool and cotton clothes?
3. Do you think the water in your town affects the cleaning efficiency of the laundry detergent?

Project 3. Homemade soap (optional)
This a fun! The method melt and pour isn't expensive and it's safe making it at home. The melt and pour base is available online.

Materials

Cutting board
Knife
Soap mold
Essential oil (lavender, vanilla etc.)
Color (optional)
Melt and pour soap base
Alcohol in spray bottle
heat resistant container

Key terms

- lipids
- fats
- oils
- fatty acids
- soaps
- detergents

Steps

1. Cut the base into small pieces.
2. Put it in the container and melt the base in the microwave.
3. Add essential oil and color it if you want. Stir it up but not hard because you might get bubbles.
4. Pour the melted, colored and fragranced base into the mold and spray with alcohol.
5. Wait for the soap to harden about an hour.

Voala! You have your first soap

Carbohydrates

28

Another important family of compounds are carbohydrates which are source of energy for the living organisms and structural material for some plants. The name carbohydrate dates back to the times when scientists thought these substances are simply hydrates of carbon. Now, we know this definition is not correct but it is the name we still use.

Classification and structure

Carbohydrates are divided into three classes – monosaccharides, oligosaccharides and polysaccharides. Monosaccharides are the simplest carbohydrates and they can't be broken into simpler carbohydrates. Depending on whether the carbonyl group in monosaccharides is aldehyde or ketone group, they are classified as aldoses and ketoses. The most important monosaccharides are glucose and fructose. They have the same molecular formula $C_6H_{12}O_6$ but different functional groups. Glucose, called aldohexose, contains an aldehyde group and fructose (ketohexose) known as fruit sugar contains a ketone group. These compounds undergo reversible reaction forming α – and β – isomers. Figure 3

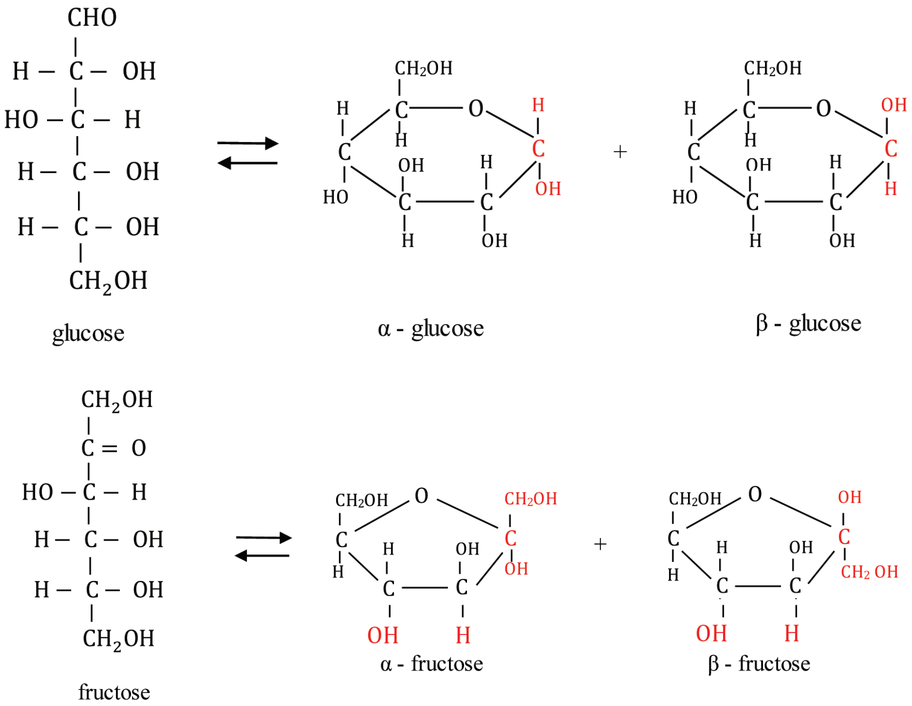


Figure 3
Forming α- and β-isomers of glucose and fructose

Figure 1
Sweets contain large amount of sugar

Figure 2
Table fructose

Key terms

- carbohydrates
- monosaccharides
- disaccharides
- polysaccharides
- glucose
- fructose
- sucrose
- starch
- cellulose
- invert sugar
- glycoside linkage

Figure 4
Sucrose crystals

Disaccharides are formed by combining two monosaccharides with elimination of a water molecule. The most important disaccharide is sugar. It is a combination of α-fructose and β-fructose bonded by what is called a glycoside linkage. (Figure 5) The enzyme α-amylase which is found in saliva, catalyzes sugars' hydrolysis. Hydrolysis of sucrose in the presence of an acid or an enzyme yields 50:50 mixture of glucose and fructose called inverted sugar is a component of honey.

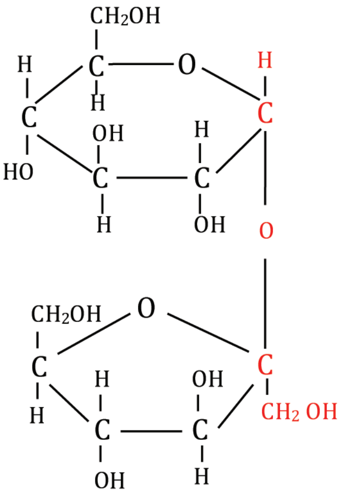


Figure 5
Glycosidic linkage in sucrose (sugar)

Figure 6
Cotton contains cellulose

Polysaccharides are formed by a polymerization of monosaccharides. The most important polysaccharides are starch and cellulose. The main component of starch is a polymer called amylose which is made up of α-glucose monomers. Growing up, plants use the starch as a food supply. When their leaf system is mature enough, they start to produce their own nutrients through photosynthesis. Cellulose consists of β-glucose monomers. The structure of cellulose and starch looks similar but only at first sight. The difference in the bonding between monosaccharides in these compounds that causes different molecular orientation. This minor difference actually has large consequences. Humans have an enzyme that can break the bond between the monosaccharides in starch so they can be used as a nutrient but we don't have an enzyme that does the same with cellulose. On the other hand, animals don't have the enzyme for ~~the~~ starch but have the one for cellulose and unlike humans, they can use cellulose as a nutrient.

Figure 7
Potato Starch

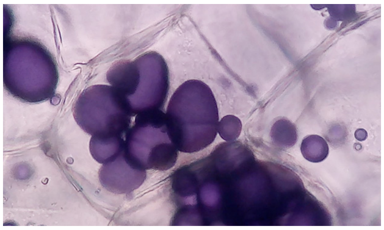


Figure 8
Starch granules of potato

Peptides and proteins

29

The German chemist Emil Fischer (Figure 1) was the first scientist who determined the overall structure of peptides and proteins. He successfully synthesized proteins, uniting various amino acids. He established that a special bond called peptide bond links the amino acids into peptides (see p. 127). Oligopeptides are molecules containing approximately 10 to 50 amino acid units. Polymers containing 40 – 10 000 or more amino acid units are called proteins. One of the earliest proteins classification is based on their solubility and classifies them as globular (soluble) and fibrous proteins (insoluble). Another important classification is based on their physiological function in the human body.

Figure 1
Emil Fischer

Problem 1. Fill the table linking the following proteins with their function
Myosin, hemoglobin, keratin, growth hormone, casein, glycoproteins, albumin, ovalbumin, antibodies, fibrinogen, collagen, insulin

Structural	***Contractile***	***Transport***	***Hormones***	***Storage***	***Protection***

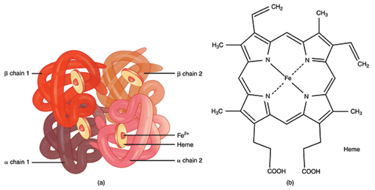


Figure 2
Hemoglobin

Proteins have four levels of structure: primary, secondary, tertiary and quaternary. (Figure 3 Proteins levels of structure). The primary structure is defined by the amino acids sequence. The secondary structure is defined by the folding of the polypeptide chain. The three-dimensional structure of a polypeptide is called tertiary structure. Tertiary structure is mainly due to the interactions between the alkyl groups of the amino acids that build up the protein. A protein may lose its three-dimensional structure which leads to loss of biological activity. The process is called denaturation. Factors that can cause denaturation are high temperature and changes in pH levels. Most of the proteins have three levels of structure and only one polypeptide chain, while others have multiple polypeptide chains (subunits). When the subunits come together, they form protein's quaternary structure.

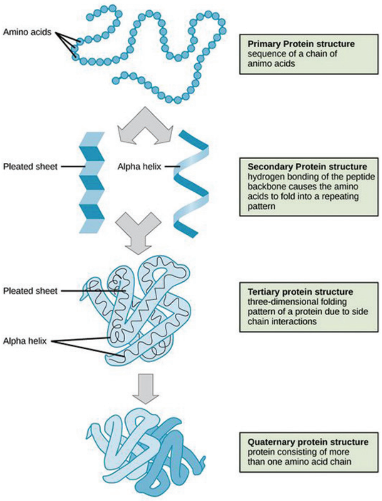


Figure 3
Proteins levels
of structure

Home project Breaking proteins

Materials

1. An egg
2. Four small glasses with the same size (one of them must be heat resistant)
3. Water

4. Alcohol
5. A fork or something to stir the samples

Steps
1. Split the yolk and the white of the egg. You will need the egg's white.
2. Separate the white of the egg into four parts and put each in a different glass.
3. Label the glasses as follows: control, alcohol, hot water, and table water.
4. Add 75 ml of an alcohol, 150 ml hot water and 150 table water to the corresponding glasses. Don't add anything to the control glass.

You can stir up your samples and observe if there are any changes.

Questions to think about….
1. What is the name of the protein that the egg white contains?
2. Do you think water itself is a denaturation agent or there is something else that makes a difference in the water sample?
3. Can you think of another protein and a denaturation agent used in daily life?
4. Why cell proteins need protection from denaturation?

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Key terms
- Peptides
- proteins
- primary structure
- secondary structure
- tertiary structure
- quaternary structure

The pharmaceutical industry. Drugs 30

For hundreds of thousands of years, people have been using medicines to treat different types of illnesses and diseases. Until the 18th century physicians used herbal medicines without knowing how and why they work. In 1780 William Withering, who was a botanist, chemist and physician successfully extracted the active ingredient from purple foxglove (digitalis purpurea), explained its effect on the human body and the best way to be used as a treatment for heart rate control. Since then, pharmacology began to develop. At the same time Wohler disproved the theory of the vital force, synthesising an organic compound out of inorganic compound which in turn was the starting point for developing organic chemistry. These breakthroughs marked the establishment of the pharmaceutical industry. In the 20th century, medications like morphine, quinine and strychnine, acetylsalicylic acid, penicillin, insulin, antibiotics, acetaminophen, ibuprofen, contraceptives and many more were discovered, which saved many people's lives.

Figure 1
Cannabis

We often use the word drugs when we talk about medicines but do you know that there is a difference between these words? A drug is a substance that controls your mind and body while a medicine is a substance that restores their normal function.

According to how they affect our body, drugs can be categorised as depressants, hallucinogens and stimulants. They all affect the nervous system making it work faster, slower or change the way we taste, smell or feel.

1. Depressants are alcohol, cannabis and opioids like heroin and morphine.

– Alcohol is a drug that affects mostly your behaviour and the way you feel. It can be toxic and addictive. Depending on how often and how much alcohol a person drinks it has short term and long term effects on health. Both put people's lives at risk and when people can't overcome the addiction, lethal consequences are possible.

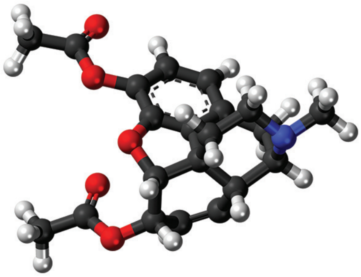

Figure 2
Heroin molecule

– Cannabis has other names as marihuana, pot and weed. It comes in different forms and it can be smoked, eaten or vaporised. More often it is smoked and leads to different experiences and effects. While using this drug, people might feel relaxed and euphoric, while others might feel anxiety and depression. Combining cannabis with other drugs like alcohol can lead to unpredictable consequences. Sometimes cannabis is used to calm down the effect of stimulants like ecstasy.

Figure 3
Heroin often is injected into a vain

– Heroin can be found in different forms – white powder, granules and light brown rock. It can be snored, but usually it is injected intravenously. Heroin's effects remain for a few hours and vary from intense pleasure and pain relief to unconsciousness. There is a huge risk of different infections because sometimes the addicts share their needles. A heroin overdose might lead to death. Combining heroin with other drugs strains organs such as the heart, kidneys, lungs, etc. Usually to help addicts give up on heroine, it is replaced by methadone.

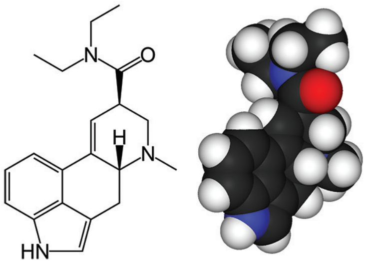

Figure 4
LSD 2D and 3D structure

2. Hallucinogens change the way you see reality. One of the most "famous" and used hallucinogens is lysergic acid diethylamide (LSD). It is a white, crystalline substance, often sold in the form of pills. This synthetic drug has a long effect – 8 to 12 hours and people experience euphoria, hallucinations, paranoia, fast breathing, increased body temperature etc. Sometimes LSD's effects can reoccur weeks, months or years after the drug has been taken. These flashbacks can be recalled by stress, exercise or using other drugs.

3. Stimulants are cocaine, amphetamines and ecstasy. The body and brain communicate more quickly when stimulants are used. It is possible for people who use these drugs to have increased alertness, confidence and energy. The effects of higher doses include paranoia, convulsions, panic attacks, and stomach pains.

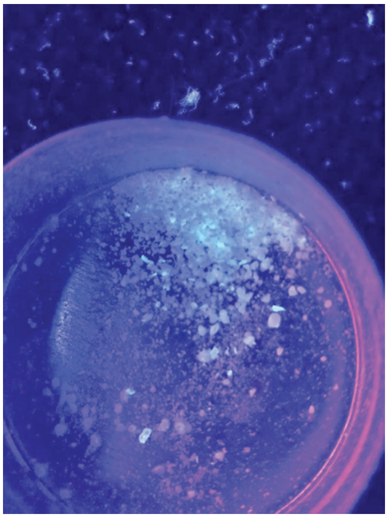

Figure 5
Cocain under the UV light

– Cocaine comes from the leaves of a plant called coca bush which grows in South America. The effects vary from happiness and confidence through anxiety, paranoia and high blood pressure to indifference to pain. Often use and high doses might lead to a condition called "cocaine psychosis". As it is with heroin, there is a huge risk of different infections. Cocaine is an addictive drug and it is very difficult to overcome the addiction.

– MDMA – methylenedioxymethamphetamine is known as ecstasy. It increases empathy and compassion towards other people. This drug is used mostly at parties, concerts and nightclubs. Its effects stay from half an hour to a few hours and people experience euphoria, sensitivity and a great thirst which can cause death.

– Amphetamines can be found in different forms from powder to pills. Sometimes they are prescribed by doctors for patients with hyperactivity disorder, narcolepsy and Parkinson's disease. Its effects can come immediately or within 30 minutes.
Some people categorise drug addiction as brain disorder or a state where a person cannot resist the impulse to consume drugs. But the truth is whatever we call it, it has severe consequences. The addiction affects not only your life but the life of each person in your family. Sometimes it looks easier to take drugs in order to escape your thoughts, feelings or you might want to try just for fun. But once you start, they will drain the life out of you. Sometimes people look for a shortcut, an easier way to "free" themselves from reality, but the truth is doing drugs is true slavery. Yes, life is hard sometimes but at the same time it has so much to offer. The worst thing we can do is to choose drugs over life.

Figure 6
Drug addict

Here are some quotes from famous people who were addicts:

"Drugs are a waste of time. They destroy your memory and yourself, respect and everything that goes along with your self-esteem."
Kurt Cobain

Figure 7
Drunk man

"Addiction is just a way of trying to get at something else. Something bigger. Call it transcendence if you want, but it's a rat in a maze. We all want the same thing. We all have this hole. The thing you want offers relief, but it's a trap."
Tess Callahan

"First you take a drink, then the drink takes a drink, then the drink takes you."
Francis Scott Key Fitzgerald

Figure 8
Ecstasy tablets

"I understood, through rehab, things about creating characters. I understood that creating whole people means knowing where we come from, how we can make a mistake and how we overcome things to make ourselves stronger."
Samuel L. Jackson's
words when struggling through addiction recovery.

Don't forget there is always hope. There is always
a solution and way out!

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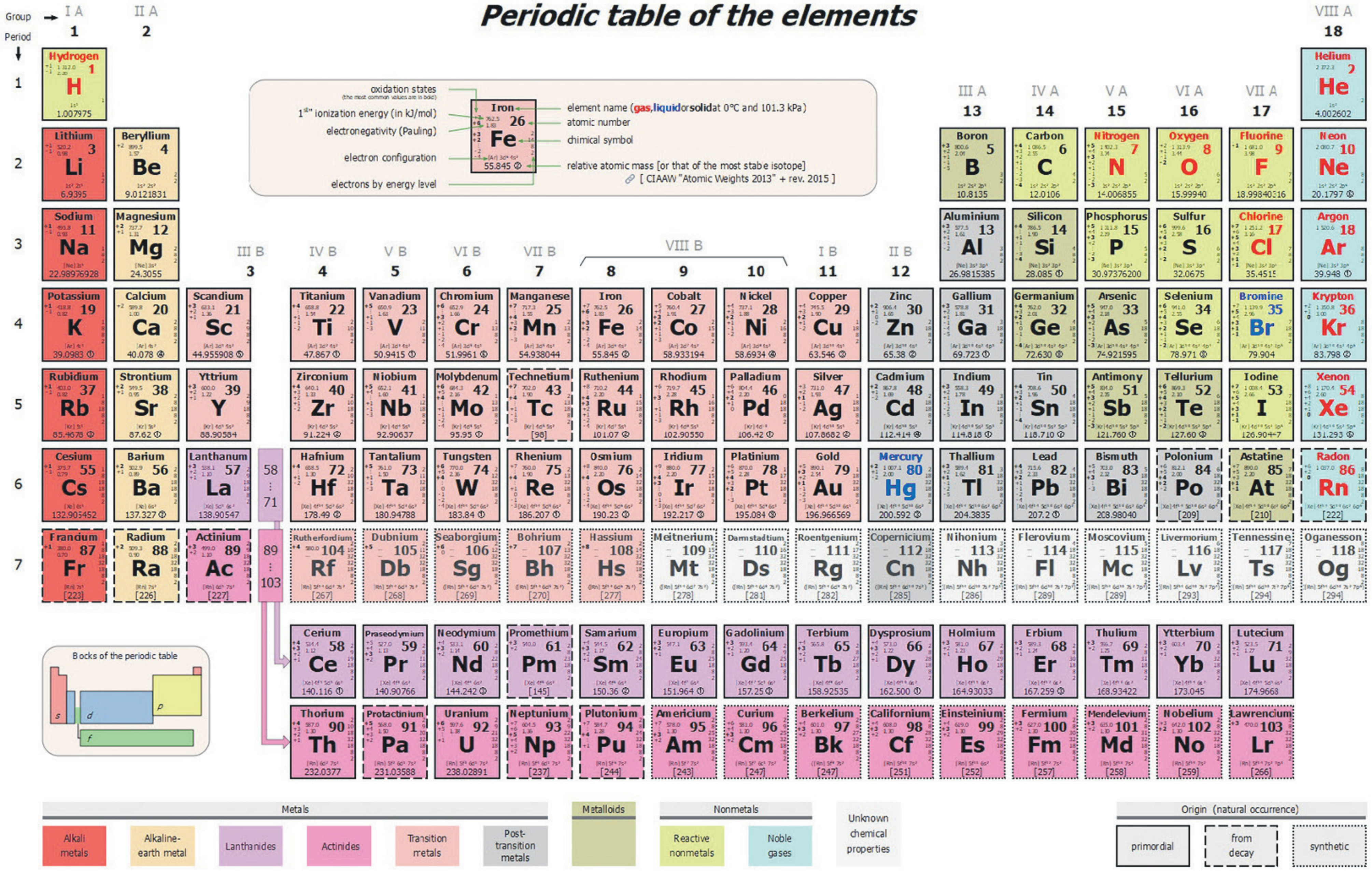
Periodic table of the elements



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1	Hydrogen 1 H 1.007975																	Helium 2 He 4.002602
2	Lithium 3 Li 6.9395	Beryllium 4 Be 9.0121831											Boron 5 B 10.8135	Carbon 6 C 12.0106	Nitrogen 7 N 14.006855	Oxygen 8 O 15.99940	Fluorine 9 F 18.99840316	Neon 10 Ne 20.1797
3	Sodium 11 Na 22.98976928	Magnesium 12 Mg 24.3055											Aluminium 13 Al 26.9815385	Silicon 14 Si 28.085	Phosphorus 15 P 30.97376200	Sulfur 16 S 32.0675	Chlorine 17 Cl 35.4515	Argon 18 Ar 39.948
4	Potassium 19 K 39.0983	Calcium 20 Ca 40.078	Scandium 21 Sc 44.955908	Titanium 22 Ti 47.867	Vanadium 23 V 50.9415	Chromium 24 Cr 51.9961	Manganese 25 Mn 54.938044	Iron 26 Fe 55.845	Cobalt 27 Co 58.933194	Nickel 28 Ni 58.6934	Copper 29 Cu 63.546	Zinc 30 Zn 65.38	Gallium 31 Ga 69.723	Germanium 32 Ge 72.630	Arsenic 33 As 74.921595	Selenium 34 Se 78.971	Bromine 35 Br 79.904	Krypton 36 Kr 83.798
5	Rubidium 37 Rb 85.4678	Strontium 38 Sr 87.62	Yttrium 39 Y 88.90584	Zirconium 40 Zr 91.224	Niobium 41 Nb 92.90637	Molybdenum 42 Mo 95.95	Technetium 43 Tc [98]	Ruthenium 44 Ru 101.07	Rhodium 45 Rh 102.90550	Palladium 46 Pd 106.42	Silver 47 Ag 107.8682	Cadmium 48 Cd 112.414	Indium 49 In 114.818	Tin 50 Sn 118.710	Antimony 51 Sb 121.760	Tellurium 52 Te 127.60	Iodine 53 I 126.90447	Xenon 54 Xe 131.293
6	Cesium 55 Cs 132.905452	Barium 56 Ba 137.327	Lanthanum 57 La 138.90547 58 ⋮ 71	Hafnium 72 Hf 178.49	Tantalum 73 Ta 180.94788	Tungsten 74 W 183.84	Rhenium 75 Re 186.207	Osmium 76 Os 190.23	Iridium 77 Ir 192.217	Platinium 78 Pt 195.084	Gold 79 Au 196.966569	Mercury 80 Hg 200.592	Thallium 81 Tl 204.3835	Lead 82 Pb 207.2	Bismuth 83 Bi 208.98040	Polonium 84 Po [209]	Astatine 85 At [210]	Radon 86 Rn [222]
7	Francium 87 Fr [223]	Radium 88 Ra [226]	Actinium 89 Ac [227] 89 ⋮ 103	Rutherfordium 104 Rf [267]	Dubnium 105 Db [268]	Seaborgium 106 Sg [269]	Bohrium 107 Bh [270]	Hassium 108 Hs [277]	Meitnerium 109 Mt [278]	Darmstadtium 110 Ds [281]	Roentgenium 111 Rg [282]	Copernicium 112 Cn [285]	Nihonium 113 Nh [286]	Flerovium 114 Fl [289]	Moscovium 115 Mc [289]	Livermorium 116 Lv [293]	Tennessine 117 Ts [294]	Oganesson 118 Og [294]
				Cerium 58 Ce 140.116	Praseodymium 59 Pr 140.90766	Neodymium 60 Nd 144.242	Promethium 61 Pm [145]	Samarium 62 Sm 150.36	Europium 63 Eu 151.964	Gadolinium 64 Gd 157.25	Terbium 65 Tb 158.92535	Dysprosium 66 Dy 162.500	Holmium 67 Ho 164.93033	Erbium 68 Er 167.259	Thulium 69 Tm 168.93422	Ytterbium 70 Yb 173.045	Lutecium 71 Lu 174.9668	
				Thorium 90 Th 232.0377	Protactinium 91 Pa 231.03588	Uranium 92 U 238.02891	Neptunium 93 Np [237]	Plutonium 94 Pu [244]	Americium 95 Am [243]	Curium 96 Cm [247]	Berkelium 97 Bk [247]	Californium 98 Cf [251]	Einsteinium 99 Es [252]	Fermium 100 Fm [257]	Mendelevium 101 Md [258]	Nobelium 102 No [259]	Lawrencium 103 Lr [266]	

oxidation states
(the most common values are in bold)
1st ionization energy (in kJ/mol)
electronegativity (Pauling)
electron configuration
electrons by energy level

Iron 26 Fe 55.845

element name (**gas**, **liquid** or **solid** at 0°C and 101.3 kPa)
atomic number
chimical symbol
relative atomic mass [or that of the most stabe isotope]
[CIAAW "Atomic Weights 2013" + rev. 2015]

Metals: Alkali metals; Alkaline-earth metal; Lanthanides; Actinides; Transition metals; Post-transition metals

Metalloids

Nonmetals: Reactive nonmetals; Noble gases

Unknown chemical properties

Origin (natural occurrence): primordial; from decay; synthetic