Institute of Mathematics,
Physics and Chemistry

Department of Chemistry

Technical chemistry laboratory

Laboratory exercise

Properties of p-block elements

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EXERCISE SHEET

<table>
<tr><td rowspan="2">1</td><td colspan="3">Relation to subjects: ESO/26, DiRMiUO/26, EOUNIE/26</td></tr>
<tr><td>Specialty/Subject</td><td>Learning outcomes for the subject</td><td>Detailed learning outcomes for the subject</td></tr>
<tr><td></td><td>ESO/25 Technical chemistry</td><td>EKP1
K_W01, K_W02, K_U05

EKP2
K_U08, K_U09</td><td>SEKP3 – carrying out reactions characteristic for selected elements of the s and p block: reactions of alkali and alkaline earth metals; reactions of metals with oxygen, reactions of metals with acids; reactions of metals with different activities.</td></tr>
<tr><td></td><td>ESO/26 Chemistry of water, fuels and lubricants</td><td>EKP3
K_U014, K_U015, K_U016.</td><td>SEKP6 – Determination of total, calcium and magnesium hardness of boiler water.</td></tr>
<tr><td></td><td>DiRMiUO/26 Chemistry of water, fuels and lubricants</td><td>EKP3
K_U014, K_U015, K_U016.</td><td>SEKP6 – Determination of total, calcium and magnesium hardness of boiler water.</td></tr>
<tr><td></td><td>EOUNiE/26 Chemistry of water, fuels and lubricants</td><td>EKP3
K_U014, K_U015, K_U016.</td><td>SEKP6 – Determination of total, calcium and magnesium hardness of boiler water.</td></tr>
<tr><td>2</td><td colspan="3">Purpose of the exercise:
1. Expanding knowledge in the field of the periodic table of elements, systematics of chemical compounds and learning the basic chemical properties of elements from blocks s and p.
2. To consolidate the ability to record chemical reactions (formation of oxides, hydroxides, acids).
3. Understanding the method of removing water hardness by chemical method and recording appropriate reactions.
4. Acquiring the ability to assess the activity of metals on the basis of the periodic table of the voltage series of metals.</td></tr>
<tr><td>3</td><td colspan="3">Prerequisites:
– general information on the periodic table of elements in macro and macroscopic terms, general chemical knowledge about selected elements of the s and p blocks.</td></tr>
<tr><td>4</td><td colspan="3">Description of the laboratory workplace:
Basic laboratory equipment – a set of test tubes in a stand, burner, laboratory tongs, platinum wire, evaporator, solutions: 0.1 M sodium hydroxide NaOH, 0.1 M magnesium chloride $MgCl_2$, 2 M ammonium chloride, 0.1 M sodium carbonate, 0.1 M strontium chloride, 0.1 M barium chloride, 0.1 M sodium sulphate(VI), 0.1 M potassium chromate(VI), 2 M acetic acid, 0.1 M calcium carbonate, 0.1 M calcium chloride, saturated solutions: barium nitrate(V), strontium nitrate(V), calcium nitrate(V), indicators: 0.05% alcohol solution of phenolphthalein, solids: magnesium ribbon.</td></tr>
<tr><td>5</td><td colspan="3">Risk assessment*:
Contact with solutions of salts, acids and bases and burning of the Mg ribbon – the likelihood of chemical or thermal burns is very low, the effects are minor.
Final assessment – MEDIUM
Security measures required:</td></tr>
</table>

	a. protective gloves, b. protective glasses, c. protective lab coats.
6	**The course of the exercise** 1. Getting to know the workplace instructions for exercises (Appendix 2), 2. Performing individual exercises in accordance with the workplace manual.
7	**Exercise report:** 1. Develop an exercise in accordance with the instructions contained in the workplace manual. 2. Solve the given task and/or answer the questions included in the set of tasks and questions to be completed by the student.
8	**Archiving of research results:** submit an exercise report in the applicable form at the beginning of the next laboratory exercises.
9	**Assessment method and criteria:** a. EKP1, EKP2 – the control of the knowledge of basic chemical concepts and the ability to use the basic periodic table to assess the chemical properties of selected elements will be carried out during classes, b. SEKP3 – the detailed effect of the student's education will be assessed on the basis of the observations, conclusions and solutions to tasks and problems given for independent solution/development: – mark 2,0 – the student has too little knowledge of the periodic table, the characteristic properties of selected elements in the s and p block and the activity of metals, or is unable to use it for simple practical tasks related to the above-mentioned issues; – mark 3,0 – has basic chemical knowledge of the periodic table and the properties of elements and a number of metal activities, and is able to use it to solve simple tasks and problems related to the above-mentioned issues; – mark 3,5 – 4,0 – has extended chemical knowledge in the field of chemical properties of elements and the periodic table and a number of activities of metals, and has the ability to solve complex tasks related to the above-mentioned issues in his specialty; – mark 4,5 – 5,0 – has the ability to apply complex chemical knowledge in the field of the properties of elements and a number of metal activities, and is able to solve complex and problematic tasks related to the above-mentioned issues in their field.
10	**Literature:** 1. Stundis H., Trześniowski W., Żmijewska S.: *Ćwiczenia laboratoryjne z chemii nieorganicznej*. WSM, Szczecin 1995. 2. Kozłowski A., Gabriel-Półrolniczak U., Ćwirko K., *Instrukcja stanowiskowa do ćwiczeń laboratoryjnych: Właściwości pierwiastków bloku s i p,* AM Szczecin, 2013. 3. Cox P.A. Translation of Z. Zawadzki: *Chemia nieorganiczna*. PWN. Warsaw 2006. 4. Drapała T.: *Chemia ogólna i nieorganiczna*. SGGW, Warsaw 1994. 5. Bielański A.: *Chemia ogólna i nieorganiczna.* PWN, Warsaw 1994. 6. Jones L., Atkins P., *Chemia ogólna*. Cząsteczki, materia reakcje, WN PWN, Warsaw 2004. 7. Mastalerz P.: *Elementarna chemia nieorganiczna*. Wydawnictwo Chemiczne. Warsaw 2000. 8. Śliwa A.: *Obliczenia chemiczne. Zbiór zadań.* PWN. Warsaw 1994.

	9. Pazdro M. *Zbiór zadań z chemii dla szkół średnich*. 10. Kozłowski A., *Materiały dydaktyczne z chemii technicznej*, developed for the purposes of auditorium classes (not published). 11. Resources Open AGH. http://open.agh.edu.pl/open2/
11	Notes

APPENDIX 1 – MANUAL

1. SCOPE OF THE EXERCISE

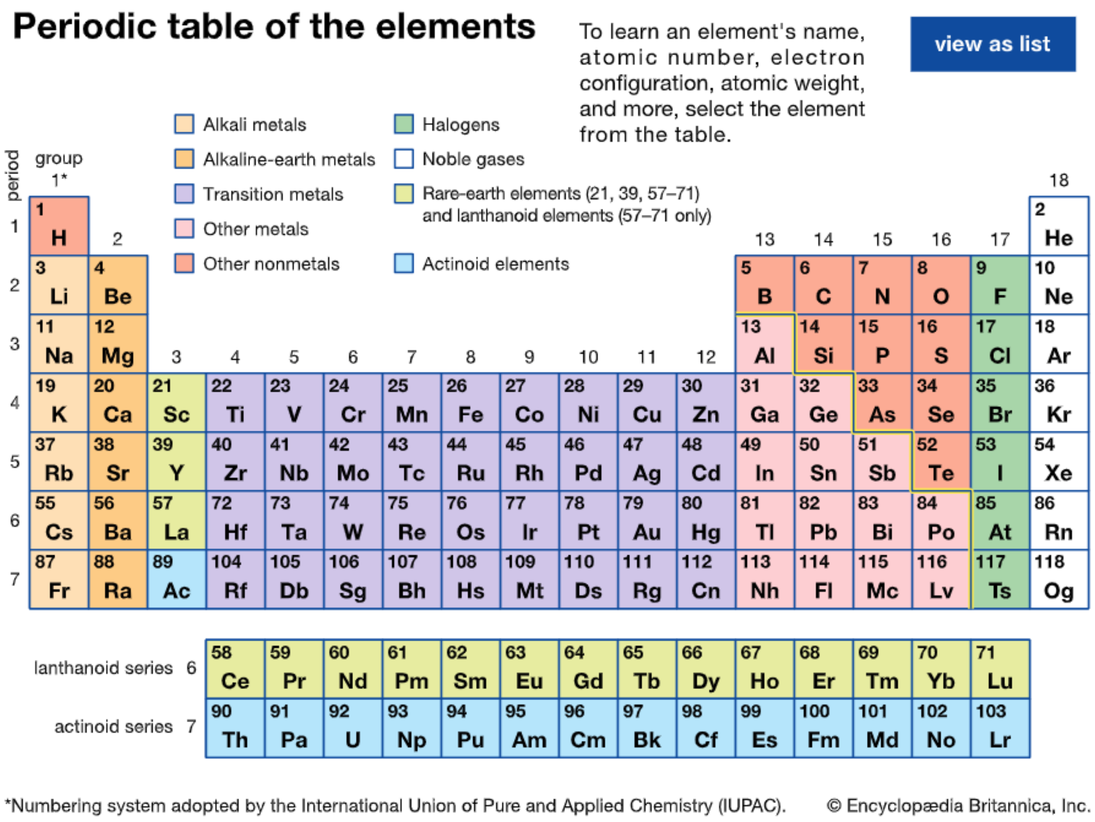
Issues and keywords:

- periodic table of elements (groups, periods, blocks of elements s, p, d, f);
- electron structure of elements (shells, subshells, Pauli exclusion principle, Hund's rules, element valence);
- chemical properties of the elements of the block p;
- systematics of inorganic compounds;
- formation of oxides, acids and salts;
- chemical activity of elements.

2. THEORETICAL INTRODUCTION TO THE EXERCISE

2.1. The law of periodicity. Periodic table

118 elements are known today, 88 of which are found in nature in an easily detectable amount. Several more have been obtained by nuclear reactions in an analytically quantifiable amount, and the few recently detected elements so far have been obtained in the smallest indeterminate amount, but nevertheless their chemical individuality has been unequivocally proven. All the elements are grouped in a table called the „Periodic Table of the Elements„. Already in the first years of the nineteenth century, attempts were made to arrange the elements in a logical way. The first attempts at systematizing the elements did not lead to satisfactory results. Such attempts were made by; Döbereiner (triads), Newlands (ranks) and Meyer (very similar to Mendeleev's system). It was not until 1870 that Mendeleev resolved the problem properly. He developed the **law of periodicity**, the later expression of which is the present periodic table, presented in a modern form in Fig. 1.



Periodic table of the elements

To learn an element's name, atomic number, electron configuration, atomic weight, and more, select the element from the table.

period	group 1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
lanthanoid series 6				58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
actinoid series 7				90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

*Numbering system adopted by the International Union of Pure and Applied Chemistry (IUPAC).

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Fig. 1. Periodic Table of the Elements
source: https://www.britannica.com/science/periodic-table
(accessed October, 1, 2021)

D.I. Mendeleev arranged the elements according to the increasing atomic mass and determined that:

- elements arranged according to increasing atomic mass show repeatability (periodicity) of their properties (the so-called law of periodicity);
- in the table of the periodic table, it leaves spaces for elements that are probably existing, but not yet discovered;
- in several places in the system, the order of the elements should be rearranged, considering that the similarity of their properties in the same group is more important than their increasing atomic mass.

The properties of the elements gradually change over the period. He placed horizontal rows of elements with repeating properties one below other. This became the basis for dividing the table of elements into eighteen vertical columns called groups of elements. All vertical groups have a name. And so, the roots of the main groups of the block p, corresponding to the group number, constitute:

– 13 – boron group	block **p**
– 14 – carbon group	block **p**
– 15 – nitrogen group (pnictogens)	block **p**
– 16 – oxygen group (chalcogens)	block **p**
– 17 – fluorine group (halogens)	block **p**
– 18 – helium group or neon group (noble gases)	block **p**

p-BLOCK ELEMENTS

2.1.3. Characteristics of the boron group

The boron group includes the following elements: **aluminium (Al), gallium (Ga), indium (In), thallium (Tl).** Group 13 also includes boron, which is a non-metal, more specifically a semi-metal. The elements of the 13th group have three valence electrons, two paired in the s orbital and one unpaired in the orbital **p** – (**s^2p^1**)

One of the most common metals of the 13th group in nature is **aluminium**. It constitutes 7.5% of the total mass of the elements included in the Earth's crust, it is third after oxygen and silicon, and the first among metals. Aluminium occurs in nature only in the form of various combinations with other elements, mainly as a component of aluminosilicates and alumina. It looks like silver. Pure aluminium is softer than iron, has high breaking and bending strength and does not show brittleness. Dissolves well in hydrochloric acid to give aluminium chloride $AlCl_3$, less in dilute sulfuric acid to form aluminium sulphate $Al_2(SO_4)_3$.

$$2Al + 6HCl \longrightarrow 2AlCl_3 + 3H_2$$
$$2Al + 3H_2SO_4 \longrightarrow Al_2(SO_4)_3 + 3H_2$$

Concentrated nitric acid does not dissolve aluminium, so aluminium tanks are perfect for the transport and storage of concentrated nitric acid. Aluminium reacts with alkali hydroxide solutions; **the reaction produces aluminates and gives off free hydrogen**

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

Aluminium is a reactive metal (note its position in the voltage series of metals); strongly heated, it burns violently in the air or oxygen. Clay dust forms an explosive mixture with air. However, under normal conditions, the aluminium quickly becomes covered with a thin, tough film of alumina which protects the metal from further corrosion. The course of the reaction is as follows:

$$2Al + 3O_2 \longrightarrow 2Al_2O_3$$

Passivation can be defined as the resistance of a metal to an oxidizing acid (or other oxidizing agent). It consists in the fact that the top layer of atoms reacts – a thin layer of a compound is formed, which no longer reacts. Regardless of the type of passivation, the idea is the same. The metal surface is in contact with another factor (e.g. air, acid) and a layer of compound resistant to further reaction is formed at the interface between these two environments. The formed oxide layer is very thin, but tight and is sufficient to prevent the metal from reacting further.

Only a few metals undergo „real" passivation – that is, they form a layer that no longer reacts. They are chromium, aluminium and titanium. Virtually any metal can be „passivated", but only with these three metals is this passivation complete, that is, a „passive" (i.e. non-reactive with the oxidizing agent) oxide is actually produced. Iron, aluminium and chromium are most often mentioned when discussing passivation. In practice, although the iron is covered with a thin layer of oxide, it still reacts (e.g. in air). Iron becomes passive only in the alkaline environment at a pH of about 11.

Sometimes it is also said about the passivation of other metals' surfaces, which takes place under the influence of oxygen from the air. Such passivation, however, usually does not completely inhibit the reaction, it only makes it more difficult. An example is the formation of a patina on the copper surface.

Patina is copper hydroxide carbonate(II): $[Cu(OH)]_2CO_3$. it can be seen in old churches with a characteristic green roof. It is formed when copper comes into contact with moisture and carbon dioxide. The process of creating a tight layer of patina lasts even several dozen years. The formed layer protects the metal, making it difficult for further reactions to take place. If there is also a lot of SO_2 in the air, then $[Cu(OH)]_2SO_4$ may be formed, but this compound does not provide any further protection. The patina can also be found on old coins made of alloys such as copper (even some old, neglected 1, 2 or 5 pennies).

2.1.4. Characteristics of the carbon group

The elements of the 14th group of the periodic table are: **carbon (C), silicon (Si), germanium (Ge), tin (Sn), lead (Pb).** In their basic state, they have the $\mathbf{s^2p^2}$ configuration. They show a tendency to both donate and take up electrons. All carbohydrates can form covalent bonds. In the group with an increase in the atomic mass, the nature of the elements changes.

Carbon. Each of the types of free carbon is of great importance as a raw material for the production of many products that find practical application in everyday life as a:

- carbon black – a product of hydrocarbon combustion, it is used as a rubber filler in the rubber production process;
- diamond – mainly used for making jewellery. Small diamonds obtained synthetically are used in the preparation of abrasives and drilling tools;
- graphite – is used in the production of lubricants, pencils, electrodes, carbon fibres and in nuclear technology;
- coke – is used in iron, zinc and lead metallurgy and as a fuel for households.

Carbon (in the form of chemicals – mainly carbon dioxide) is used as:

- extinguishing agent (snow extinguishers);
- refrigerant, the so-called „dry ice”;
- raw material for the production of urea.

Silicon. Due to its indirect (non-electronic) electric conduction properties, pure silicon is used in semiconductor electronics. Here it is used as a component of many semiconductor elements used in the production of many electronic components, RTV equipment, computers, etc. It is used as an additive to iron and aluminium alloys, improving their mechanical properties and corrosion resistance. However, the greatest application is silicon in the form of chemical compounds such as silicon dioxide (SiO_2) and aluminium silicates. They all occur in nature and silicon dioxide is the most abundant chemical compound in the lithosphere (approx. 12%).

Germanium belongs to the elements whose content in the upper layer of the Earth is very small (0.00015%). Free germanium with minimal admixtures of other elements, e.g., arsenic, exhibits semiconductor properties, therefore it has found wide application in electronics; It is used to build semiconductor elements. Germanium compounds are similar in their chemical composition to carbon compounds.

Tin is a metal that has been known for a very long time. The most important naturally occurring tin mineral is tin (IV) oxide, known as cassiterite. From it, after removal of sulphur and arsenic (by calcining), metallic tin is obtained. The process is going according to the equation.

$$SnO_2 + 2C \longrightarrow Sn + 2CO$$

Tin comes in two allotropes, **white tin** and **grey tin**. An alloy of tin with copper containing 4 – 20% tin and copper is called **bronze**. It played a significant role in the development of humanity's monetary culture. In compounds, tin appears as bi- or quadripositive.

Lead occurs in nature mainly as a mineral called PbS **galena** and as $PbCO_3$ cerusite. It is obtained in a pure state in the process:

$$2PbS + 3O_2 \longrightarrow 2PbO + 2SO_2$$
$$2PbO + PbS \longrightarrow 3Pb + SO_2$$

Lead (II) oxide can also be reduced with coke:

$$PbO + C \longrightarrow Pb + CO$$

and the obtained metallurgical lead is usually refined – mainly re-silvering and darsening. Lead and lead compounds are poisonous. In the body, lead builds up in the spinal cord, displacing calcium from its compounds. Working in the production or processing of lead can cause an occupational disease called lead.

2.1.5. Characteristics of nitrogen group (pnictogens)

The 15th group of the periodic table, the so-called pnictogens, includes: **nitrogen (N), phosphorus (P), arsenic (As), antimony (Sb), and bismuth (Bi).** In the ground state, they have the **s^2p^3**, configuration, i.e., they have one more electron than carbonates, and thus show a more electronegative nature. The highest oxidation state they can achieve is +V. In most compounds, these elements occur at +V, +III, and also at –III oxidation state, in line with the generally noticeable regularity that the chemical elements of odd groups are usually found in odd degrees of oxidation, and the chemical elements of even groups are at even degrees. Elements belonging to this group form **phosphides, arsenides, antimons and bismuths**, which undergo hydrolysis in water with the release of hydrides (**XH_3**). Antimony and bismuth hydrides are very unstable. The nature of nitrides varies from non-metallic (nitrogen, phosphorus) to metallic (bismuth), therefore nitrogen, phosphorus and arsenic oxides are acidic, antimony oxide is amphoteric, bismuth oxide is basic.

Nitrogen is the main component of air (78 vol% of the atmosphere). It is almost insoluble in water, it is an inert gas, it does not react very readily, which is related to the triple bond in the N_2 molecule. It is practically inactive at room temperature, but reacts at elevated temperatures. The compounds occur in the oxidation states from –III (ammonia) to +V (nitrate ion). Important nitrogen compounds are:

- **ammonia** (**NH_3**) – irritating, toxic gas, due to its smell, can be used to awaken people;
- **hydrazine** (**NH_2NH_2**) – oily, colourless liquid, is explosive, used as rocket fuel, and also as an additive to water used in steam boilers to remove oxygen, the presence of which accelerates corrosion;
- **hydrogen azide** (**HN_3**) – parent compound of azides, e.g. **NaN_3** – sodium azide, **$Pb(N_3)_2$** – lead azide – used as an explosives detonator;
- **nitrogen (I) oxide** (**N_2O**) – nitrous oxide, non-toxic, can be used as a foaming agent for whipped cream;

- **nitrogen (II) oxide** (**NO**) – contributes to the formation of acid rain, smog and the destruction of the ozone layer, synthesized in negligible amounts in the human body participates in physiological changes that accompany sexual arousal;
- **nitrogen (IV) oxide (NO_2)** – brown, suffocating, poisonous gas affects the colour and smell of smog;
- **nitric acid (III)** (**HNO_2**) (nitrous acid) – widely used in the form of an aqueous solution in the processing of meat products – forms a pink complex with haemoglobin, which prevents browning of the meat;
- **nitric acid** (**V**) (**HNO_3**) (nitric acid) – colourless liquid, strong oxidizer, mainly used in the production of fertilizers and explosives.

Nitrogen reacts with metals to form nitrides. It forms nitrides with elements III, IV and V groups, which are durable and fireproof, with transition metals (IV and VI subgroups), very durable nitrides, which have high boiling points, are chemically inactive (steel cementation consists in the production of a surface layer of nitride interstitial). The nitrides of lithium, alkaline earths and zinc metals have an ionic nature – they decompose with water and release ammonia.

Free **phosphorus** is obtained from apatites, which are the mineral forms of calcium phosphate $Ca_3(PO_4)_2 \cdot H_2O$, by roasting with sand and coal.

$$2Ca_3(PO4)_2 + 6SiO_2 \longrightarrow 6CaSiO_3 + P_4O_{10}$$
$$P_4O_{10}(g) + 10C \longrightarrow P_4(g) + 10CO$$

Phosphorus comes in several allotropic forms, as **white, red, purple and black phosphorus**.

White phosphorus is poisonous and chemically active (ignites itself in air and becomes P_2O_5 oxide). Under the influence of light and heat, it turns into red phosphorus, which is non-toxic and less active. White phosphorus is used as an incendiary for inlet incendiary bombs (napalm). Red phosphorus is used in potting mixes in matchboxes. Upon heating (t = 530°C), violet phosphorus is obtained. The most durable type of phosphorus is **black phosphorus**, which is obtained by recrystallization of white phosphorus under high pressure or in the presence of mercury acting as a catalyst.

As a result of phosphorus combustion with limited oxygen supply, P_2O_3 (phosphorus trioxide) is formed. Both P_2O_5, and P_2O_3 are dimers and their correct formulas are: P_4O_{10} i P_4O_6, for simplicity, however, monomeric formulas are used. Phosphorus(III) oxide is phosphoric acid anhydride (H_3PO_3). Orthophosphoric acid is obtained by dissolving phosphorus pentoxide (P_2O_5) in water or red phosphorus in concentrated nitric acid:

$$3P + 5HNO_3 + 2H_2O \longrightarrow 3H_3PO_4 + 5NO$$

P_2O_5 derivatives (less hydrated) are pyrophosphoric acid ($H_4P_2O_7$) and metaphosphoric acid (HPO_3). The less persistent phosphorus compounds include: phosphites (derived from H_3PO_4 acid), hypophosphites (e.g. NaH_2PO_2-reducer) and phosphine (PH_3), which is a poisonous gas with a delicate garlic odour. Phosphorus can also react with chlorine. The most important phosphorus halides are: **phosphorus trichloride** (PCl_3) and **phosphorus pentachloride** (PCl_5; obtained by the reaction of phosphorus trichloride with chlorine). Phosphorus trichloride is an important intermediate in the production of pesticides, flame retardants, and additives to oils.

Arsenic, Antimony occur in the form of sulphides, in the natural state: As_4S_4 (realgar), As_2S_3 (aurypiment), FeAsS (arsenopyrite), Sb_2S_3 (antimonite). Arsenic is found in several allotropic varieties (**arsenic grey, yellow, black**), **grey arsenic** is the most durable. **Bismuth** occurs as a sulphide and an oxide: Bi_2S_3, Bi_2O_3 (bismuth ochre). Arsenic and antimony are semi-metals and are constituents of lead alloys that are used as electrodes in accumulators. Bismuth is a component of indigestion-relieving drugs and low-melting alloys.

Arsenic, antimony and bismuth form compounds in the + III and + V oxidation state. Combustion with oxygen to form trioxides (**As_2O_3 – arsenic; Sb_2O_3; Bi_2O_3**), which are transformed into pentoxides under the influence of strong oxidants (e.g., concentrated HNO_3). Arsenic and antimony also react with chlorine to form trichlorides and pentachlorides (**$AsCl_3$; $AsCl_5$; $SbCl_3$; $SbCl_5$**).

2.1.6. Characteristics of oxygen group (chalcogens)

The group 16 of the periodic table, the so-called groups of chalcogens, includes: **oxygen (O), sulphur (S), selenium (Se), tellurium (Te) and polonium (Po)**. Elements belonging to this group have in the basic state the electron configuration **ns^2np^4** and are called aerobes or chalcogens (the Greek „cuprous" – elements of this group occur in copper ores). The electronegativity of the aerobes decreases towards the bottom of the group, while their metallic character increases. Aerobes react with hydrogen, the most important compound is water (**H_2O**), equally important hydrogen peroxide (H_2O_2), which is a light blue liquid heavier than water. It is a strong oxidant. It is commercially used in the form of a 30% solution, for lightening hair (6% solution), to combat environmental pollution (used as an oxidant). **H_2X**, compounds, i.e., compounds of oxygenates – **X** with hydrogen, with the exception of water, **are poisonous gases with a pungent smell**. They paralyze the human olfactory nerve, which results in a loss of smell after a short time.

Oxygen is the most abundant element in the earth's crust, it accounts for 23% by weight of the atmosphere, the content in water is 89% by weight. It is a colourless, odourless and tasteless gas. It is composed of O_2 molecules. On a technical scale, oxygen is obtained by fractional distillation of condensed air, as well as by electrolytic decomposition of water, which produces hydrogen at the cathode and oxygen at the anode. In laboratory conditions, it is usually obtained by thermal decomposition of potassium chlorate ($KClO_3$) with the participation of a catalyst – MnO_2. Oxygen, with the exception of noble gases, forms compounds with all elements of the periodic table. It mainly occurs in –II oxidation state, less often in –I (**peroxides**), and in + II (**F_2O**).

The allotropic form of oxygen is ozone (O_3), which is formed in the stratosphere as a result of the action of solar radiation on O_2 molecules and during electrical discharges. Its pungent smell occurs, inter alia, after a lightning strike, its presence in the air is one of the reasons for the „fresh" smell of the air after a storm and the accompanying heavy rain. Ozone is a blue gas that can be obtained under laboratory conditions by causing electrical discharges in oxygen. Ozone condenses at –112°C into an explosive dark blue liquid. Ozone also appears in smog-prone areas.

Sulphur is widespread in the earth's crust mainly in the form of sulphates (galena, PbS; cinnabar, HgS; pyrite, FeS_2; sphalerite, ZnS; gypsum $CaSO_4 \cdot 2H_2O$; anhydrite $CaSO_4$; barite $BaSO_4$; pyrrhotite FeS). It is a by-product of metallurgical processes, including the process of obtaining copper from its sulphide ores. It is obtained in large amounts using the ***Claus process*** to remove sulfur compounds from crude oil.

Sulphur from deposits is obtained by the ***Frasch process***. In this method, superheated water and compressed air are forced into the bed through concentric pipes, causing the sulfur (molten) to rise to the surface. Sulphur is used to obtain sulfuric acid and vulcanize rubber.

Elemental sulphur is a yellow crystalline substance. It does not dissolve in water, but dissolves well in organic solvents such as: **benzene, diethyl ether**.

Sulphur in compounds is bi-negative (sulphides, hydrogen sulphide), tetrafositive (sulphites) and six-positive (sulphates). The reaction of sulphur with hydrogen produces hydrogen sulphide**, H_2S**, which is a highly poisonous gas. Hydrogen sulphide acid is a weak acid. The most durable sulphur compounds are **sulfuric(VI) acid and sulphates(VI)**.

Selenium and tellurium are present in sulphide ores. They are obtained from anode sludge that is formed during the electrolytic refining of copper. Selenium forms selenides Se^{2-}, selenine SeO_3^{2-} and selenates SeO_4^{2-}. The most persistent compounds are selenites. Hydrogen selenide (H_2Se) resulting from the decomposition of metal selenides is a gas with an odor similar to hydrogen sulphide, but more poisonous and less persistent – it is easily oxidized to selenium.

Tellurium creates tellurides (Te^{2-}), tellurines (TeO_3^{2-}) and telluranes (TeO_4^{2-}). Tellurium compounds are less stable than selenium compounds. Hydrogen telluride (H_2Te) is a poisonous gas with a strong, unpleasant odour, it is less persistent than hydrogen selenide.

Selenium and tellurium are used in photoelectric instruments and photocopiers because of their conductivity, which increases in the presence of light. Both selenium and tellurium are used in the production of photocells and AC rectifiers.

2.1.7. Characteristics of fluorine group (halogens)

The 17th group – halogens includes the following elements: **Fluorine (F), Chlorine (Cl), Bromine (Br), Iodine (I), Astatine (At)**. In the basic state, they have the **s^2p^5** configuration. All halogens are non-metals. Under normal conditions, **chlorine and fluorine are gases, bromine is a liquid and iodine is a solid**. Halogens are highly electronegative elements and are characterized by high electron affinity. In nature, they occur mainly in the –I oxidation state in the form of alkali and alkaline earth salts. Chlorine, bromine and iodine in compounds with oxygen also occur in higher oxidation states: +I, +III, +IV, +V, +VII.

In the free state, they exist in the form of diatomic particles. Together they form interhalide compounds in the form: **AX, AX_3, AX_5, AX_7**, where **A** is the heavier (larger atoms) halogen. Bromine and iodine can attach more halogens to form the compounds **AX_5, AX_7**.

Halogens react with hydrogen to give hydrogen halides (**HF; HCl; HBr; HI**). Hydrogen halides are colourless gases with a pungent odour. Only hydrogen fluoride is liquid at temperatures below 20°C. Hydrogen halides dissolve in water. Oxygen compounds of halogens, with the exception of ClO_2, exist in odd oxidation states (+I, +III, +V, +VII). Under normal conditions, only two oxides are thermodynamically stable: **F_2O** (gas) and **I_2O_5** (solid), remaining on contact with organic substances with reducing properties, impact or heating, decompose leading to an explosion.

Fluoride is a green-yellow gas with a characteristic, penetrating smell. It occurs in minerals, including fluorite (CaF_2), cryolite (Na_3AlF_6), or fluoroapatites ($Ca_5F(PO_4)_3$). The largest amounts of this element are used to obtain the volatile UF6 substance used for the separation of uranium isotopes. Fluoride is also used to produce sulphur hexafluoride, which is used as an insulator in electrical appliances.

Free fluorine is very reactive, which makes it easy to enter into exothermic reactions with other elements and compounds. **It is the most electronegative element**, i.e., it has the greatest ability to receive electrons from atoms of other elements. In compounds it occurs only **in -I oxidation state**. Fluorine also has the ability to form strong hydrogen bonds. It can be obtained free as a result of fluoride electrolysis:

$$\text{Anode: } 2F^{-} \longrightarrow F_2 + 2e^{-}$$

It reacts violently with hydrogen to give hydrogen fluoride HF:

$$F_2 + H_2 \longrightarrow 2HF$$

Hydrogen fluoride „attacks” glass and silica, and in combination with ammonium fluoride it is used to tarnish the inside of light bulbs and etch glass. Fluorine in combination with chlorine (trifluoride chloride) was used during World War I as one of the combat gases. This compound is very active, it ignites wood, paper, and „attacks” iron and steel.

Chlorine is a poisonous gas (Cl_2) with a pungent odour and a greenish yellow colour. It is obtained from sodium chloride by electrolysis of brine or molten rock salt. It is used, among others, in the production of plastics, pesticides, solvents. It can also be used as a bleaching agent in the textile and paper industries, and also as a water disinfectant. The specific smell of chlorinated water comes from amines ($–NH_2$ groups are chlorinated).

In compounds, they are found in various degrees of oxidation under traditional names: –I (chlorides; Cl^{-}), +I (hypochlorites; ClO^{-}), +III (chlorites; ClO_2^{-}), +V (chlorates; ClO_3^{-}), +VII (perchlorates; ClO_4^{-}). Hypochlorites are mainly used as bleaching and oxidizing agents, as well as water disinfectants, especially in domestic swimming pools (**sodium hypochlorite, calcium**). Hypochlorites and chlorites are not very stable and can slowly transform into chlorates and chlorides. **Chlorates** are oxidizing agents and are, inter alia, a source of oxygen in fireworks and Swedish matches (potassium chlorate).

Chlorine is also part of such oxygen acids as:

- $HClO$ chloric acid (I) weak acid (hypochlorous acid),
- $HClO_2$ chloric acid (III) weak acid (chlorous acid),
- **$HClO_3$ chloric acid (V) strong acid (chloric acid),**
- **$HClO_4$ chloric acid (VII) strong acid (perchloric acid).**

Chloric acid(VII) and chlorates(VII) are strong oxidants – they are used in shuttle engines.

Bromine is a heavy, fuming liquid with a pungent, penetrating odour and red-brown colour, composed of particles (Br_2). Causes corrosion. It is a strong oxidant. It easily attaches and detaches from organic compounds, which is used in the chemical industry – in complex syntheses. The most stable bromine compounds include: **bromides** (Br^{-}; oxidation state –I) and **bromates** (BrO_3^{-}; oxidation state +V). Bromates are used in bromianometry, the department of quantitative analytical chemistry, these compounds oxidize, among others, a number of organic dyes – the disappearance of colour during titration with a bromate solution indicates the appearance of the BrO_3^{-} or Br_2 ion in the solution. Another bromine compound is hydrogen bromide (**HBr**). Aqueous HBr is a strong acid.

Bromine compounds are used as flame retardants (organic bromides are introduced into textiles), and also as pesticides. Inorganic bromides (especially silver bromide – **AgBr**) are used to make photographic emulsions, a saturated aqueous solution of **zinc bromide** is applied to control oil leakage from deep wells.

Iodine is a violet-black substance with a metallic sheen. It sublimes easily and is quite volatile at room temperature. It boils at 185°C and produces purple vapor. It is a weaker oxidant than other halogens. The oxidation states of iodine are: I^{-} (iodides), +V (iodates; IO_3^{-}) and +VII (periodates; IO_4^{-}). Hydrogen iodine (HI) aqueous solution is a strong acid, but compared to hydrochloric acid and hydrobromic acid, it is the least stable, which means that it is oxidized most easily – oxygen from the air oxidizes HI to iodine which turns hydroiodic acid solutions yellow:

$$4HI + O_2 \longrightarrow 2I_2 + 2H_2O$$

With the ions of silver, copper(I), mercury(I), thallium(I), bismuth and lead, iodides form sparingly soluble compounds.

Iodine dissolves in organic solvents – in chloroform and benzene it dissolves violet. Alcoholic (iodine) and aqueous iodine solutions are brown in color. The solubility of iodine in water is limited.

Iodine is an admixture in Chilean nitrate, and is also present in brines in the form of iodide ions. An alcoholic iodine solution (iodine) is used as a disinfectant. Iodine, as a trace element, is necessary for the proper functioning of living organisms, its lack or excess causes serious diseases of the thyroid gland.

2.1.8. Characteristics of the helium group or neon group (noble gases)

The group 18 of the periodic table includes noble gases; **helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), radon (Rn)**. They occur in the atmosphere as monatomic, non-reactive gases. Noble gases, apart from helium and radon, are obtained by distilling liquid air. Helium atoms are very light, many of them reach high velocity and „escape" from the atmosphere, which means that helium is rare on Earth. However, it is a component of natural gas in North America. This gas is released on an industrial scale by liquefaction and fractional gas distillation. Radon is a radioactive gas and a product of radioactive processes deep within the Earth. It can be found in small amounts in mineral waters.

Heliums have been widely used, among other things, they are used to cool superconducting devices (**helium, neon**), they are used as protective gases during smelting and welding (**argon**) of some metals (e.g., magnesium, stainless steel), for diluting oxygen in deep diving, for maintaining rocket fuel pressure (**helium**) and filling the interior of high-power light bulbs. As a result of excitation with an electric field, they emit light: helium – yellow light, neon – red-orange light, argon – red or blue light, xenon and krypton – white light.

Thanks to the emission of red light, **neon** is used in illuminated advertisements.

Krypton (white light emission) is used to illuminate the runways at the airport. **Xenon** is applied in halogen bulbs for car headlights, as well as in photographic flash lamps.

Noble gases are chemically inactive, have low boiling and melting points, and in the gaseous phase their atoms do not combine into diatomic molecules due to the complete filling of the s and p subshells. Noble gas compounds can only exist under special conditions. Only xenon forms compounds with oxygen and fluorine. Xenon oxides (XeO_3) are very strong oxidants, while xenon fluorides (XeF_4) are classified as strong fluorinating agents.

Selected chemical reactions of p-block elements leading to the formation of binary and oxoacids

Selected oxoacids are formed in the reaction of a **non-metal oxide with water**, otherwise **an acid oxide with water**, examples of the reaction of obtaining selected oxygen acids:

$SO_2 + H_2O \rightarrow \mathbf{H_2SO_3}$ sulphuric acid (IV) (sulfurous acid)
$SO_3 + H_2O \rightarrow \mathbf{H_2SO_4}$ sulphuric acid (VI) (sulfuric acid)
$N_2O_5 + H_2O \rightarrow 2\mathbf{HNO_3}$ nitric acid (V) (nitric acid)
$N_2O_3 + H_2O \rightarrow 2\mathbf{HNO_2}$ nitric acid (III) (nitrous acid)
$CO_2 + H_2O \rightarrow \mathbf{H_2CO_3}$ carbonic acid
$P_4O_{10} + 6\ H_2O \rightarrow 4\ \mathbf{H_3PO_4}$ phosphoric acid (V) (also orthophosphoric acid)

Binary acids are formed in a chemical reaction: hydrogen + non-metal, as a result of a chemical reaction, a gas is formed, which when dissolved in water gives a binary acid e.g.

$H_2 + Cl_2 \rightarrow 2\ \mathbf{HCl}$ hydrogen chloride (gas), further dissolved in water, forms hydrochloric acid $\mathbf{HCl}_{aq}$

$H_2 + S \rightarrow \mathbf{H_2S}$ hydrogen sulphide (gas), further dissolved in water, forms hydrosulfuric acid $\mathbf{H_2S}_{aq}$

3. PERFORMING THE EXERCISE

Experiment 1 – Burning sulphur, reaction of non-metal oxide with water

Materials and reagents:

Solid sulphur, combustion spoon, laboratory gas burner, distilled water, solution of universal indicator

Performance:

Ignite a small amount of sulphur in the flame of the laboratory gas burner on a combustion spoon and quickly transfer the spoon with the burning sulphur to the inside of the Erlenmayer conical flask, previously rinsed inside with distilled water. Then add a small amount of distilled water and add a few drops of universal indicator, record the colour of obtained solution and check the pH value (based on the Yamada's table).

Colour change of the universal indicator according to Yamada depending on the exponent of the concentration of the hydronium ion (depending on the pH)

pH	Colour of the indicator
4.0	red
5.0	orange
6.0	yellow
7.0	green
8.0	blue
9.0	dark blue
10.0	purple

Elaboration of the results:

1. Describe the observed phenomenon.
2. Write down the reactions from the experiment performed.
3. Explain the change in the pH of the solution.
4. What's the product of the reaction?
5. What should be carried out next and under what conditions in order to obtain H_2SO_4 as a product of the reaction?

Experiment 2 – Reactions of aluminium with given salts ($CuSO_4$ and $CuCl_2$)

Materials and reagents:

Test tubes, aluminium foil, copper(II) sulphate (1% $CuSO_4$) solution, copper(II) chloride solution (1% $CuCl_2$), sodium chloride (solid) (NaCl).

Performance:

Pour about 5 cm^3 of copper(II) sulphate (1% $CuSO_4$), into the first test tube, and the same amount of copper(II) chloride solution (1% $CuCl_2$) into the second test tube. Then add a piece of aluminium foil to both test tubes. Observe the speed of the reaction and the changes taking place in both tubes. After a few minutes, add a pinch of sodium chloride (NaCl) into the first test tube and observe its effect on the reaction.

Elaboration of the results

1. Write down chemical reactions.
2. Explain the differences in the speed of the reaction in both test tubes (no salt added) using your knowledge regarding aluminium passivation.
3. What was the effect of the addition of NaCl on the rate of the reaction taking place in the first test tube (1a) and what was the role of Cl^- chloride ions in the solution?

Table of results for experiment 2

No.	Content	Initial colour	Final colour	More active metal	The ongoing reaction	Reaction rate (high/low)	Ions that stimulate the reaction
1.	copper(II) sulphate(VI) +Al						
1a	copper(II) sulphate(VI) + Al + sodium chloride						
2.	copper(II) chloride +Al						

Experiment 3 – Precipitation of aluminium hydroxide

Materials and reagents:

Rack with test tubes, aluminium sulphate solution (0.1M $Al_2(SO_4)_3$), hydrochloric acid solution (2 M HCl), sodium hydroxide solution (2 M NaOH).

Performance:

Add a few drops of aluminium sulphate (0.1 M $Al_2(SO_4)_3$) and a few drops of sodium hydroxide solution (2 M NaOH), into two test tubes until a precipitate of aluminium hydroxide is formed in both test tubes. Add hydrochloric acid solution (2 M HCl), dropwise to one test tube, and sodium hydroxide (2 M NaOH) to the other test tube. Observe what happens.

Elaboration of the results

1. Write down the molecular and ionic precipitation reactions of aluminium hydroxide.
2. Write a dissociation reaction of aluminium hydroxide.
3. Write the molecular and ionic equations between hydrochloric acid and aluminium hydroxide and also between sodium hydroxide and aluminium hydroxide.

4. DEVELOPMENT OF THE EXERCISES

1. Prepare a report according to the guidelines in the experimental section.
2. Place the cover sheet as the first page of the report.
3. After the theoretical part has been concisely developed, include in the report the study of individual experiments and the solved task/additional tasks given by the academic teacher.

5. THE FORM AND CONDITIONS FOR PASSING THE LABORATORY EXERCISE

1. Passing the so-called „entry test” before starting the exercise.
2. Submission of a correct written laboratory report on the performed exercise in accordance with the guidelines for the preparation of the laboratory report, please see the link below: https://www.am.szczecin.pl/en/facilities/institute-of-mathematics-physics-and-chemistry/department-of-chemistry/technical-chemistry/tech-chemistry-lab-manuals/

I. Examples of a task with a solution

Task Write an electron shell configuration for a tin atom:

Answer: ${}_{50}\mathrm{Sn}\ K^{2}\ L^{8}\ M^{18}\ N^{18}\ O^{4}$

Where did this answer come from?
Keep in mind that:
Period number = the number of electron shells i.e. K, L, M, etc.
Group number = number of valence electrons
Names of electron shells: **K, L, M, N, O, P, Q**
The maximum number of electrons in the shell – $\mathbf{2n^2}$, where **n** is the shell number.

K – 2 electrons
L – 8 electrons
M – 18 electrons
N – 32 electrons
O – 50 electrons
P – 72 electrons
Q – 98 electrons

For the elements of the main groups, i.e. the group: **1, 2, 13, 14, 15, 16, 17, 18, one can write the shell electron configuration** following the next rules: a) we locate a given element in the periodic table, we need to know the group number and the period number, as well as the atomic number, b) enter the group number for the last shell, then take the maximum number of electrons allowed by the formula $\mathbf{2n^2}$ for the remaining shells, except for the **penultimate one**. The number of electrons in the penultimate shell is calculated according to the formula: atomic number – the number of electrons on the shells already occupied.

II. Tasks and questions to be completed by the student

1. Write down the electron shell configuration for the given atoms:
    a) phosphorus atom,
    b) iodine atom,
    c) lead atom.
2. Complete the given chemical reactions and balance them by writing the proper stoichiometric coefficients:
    $SO_2 + O_2 \longrightarrow$
    $SO_3 + H_2O \longrightarrow$
    $Cu + H_2SO_{4\ con.} \longrightarrow$
3. Complete the chemical reactions and balance them by writing the proper stoichiometric coefficients:
    $Fe + HCl \longrightarrow$
    $Zn + Pb(NO_3)_2 \longrightarrow$
    $Al + HCl \longrightarrow$
4. Using the electronegativity table, calculate the electronegativity difference between carbon and oxygen, then determine the type of chemical bond in carbon dioxide.
5. Knowing that passivation of chromium and iron is similar to that of aluminium – reverse the passivation reactions that take place during the treatment of chromium and iron with concentrated and dilute nitric acid (V).
6. A nickel plate weighing 150 g was immersed into the $AgNO_3$ solution. The weight of the sample after removing the solution, washing and drying was 158 g. How many grams of silver were released on the nickel plate?