**Levitin Ye.Ya., Vedernikova I.O., Klimenko L.Yu., Kryskiv O.S.**

# GENERAL AND INORGANIC CHEMISTRY LABORATORY PRACTICUM

**Name:** _____,

**1ST YEAR, GROUP _____**

UDC  546 (076)
BBK  24.1

**Authors:** Ye.Ya. Levitin, I.O. Vedernikova, L.Yu. Klimenko, O.S. Kryskiv

**Reviewers:**

*G.O. Syrova,* D.Sc. in Pharmacy, Professor, Head of the department of Medicinal and Bioorganic Chemistry of Kharkiv National Medical University;

*I.O. Zhuravel,* D.Sc. in Chamistry, professor, Head of the Department of Clinical Biochemistry, Forensic Toxicology and Pharmacy of Kharkiv Medical Academy of Postgraduate Education;

*L.G. Budanova,* D.Sc. of pedagogical sciences, associate professor, Head of the department of Foreign Languages of NUPh.

**Approved by the Central Methodological Commission of the National University of Pharmacy**
(letter № 2 from 11.02.2020)

Levitin Ye. Ya., Vedernikova I. O., Klimenko L. Yu., Kryskiv O. S. General and inorganic chemistry. Laboratory Practicum. – Kharkiv, 2020. – 106 p.

The textbook was prepared in accordance with the "Work Program in General and Inorganic Chemistry" and is recommended for foreign students of higher education of pharmaceutical universities and pharmaceutical faculties of medical universities of III-IV level of accreditation. The textbook contains questions for auditorium and independent work, as well as methods for carrying out laboratory works.

**UDC 546 (076)**
**BBK 24.1**

# Preface

This textbook has been created by the faculty of the National Pharmaceutical University for university-level students majoring in Pharmacy, Clinical Pharmacy, Perfumery and Cosmetics Technology, Pharmaceutical Preparations Technology and Biotechnology.

In training pharmacists, Inorganic Chemistry provides a theoretical basis for the acquisition of Major-related subjects, as well as contributes to the development of skills to predict properties and reactionary ability of inorganic substances used in Pharmacy and Medicine. In addition, the textbook has taken into account the areas necessary for the further study of Analytical, Organic and Physical Chemistry. These factors predetermined the subject-matter of each chapter.

Preparing for the lesson, the student should familiarize himself with theoretical questions on the topic, study the material on the textbook and lectures. For a better understanding of the topic, the student must learn the basic keywords and definitions and only after that proceed with homework. If a laboratory work is planned in the lesson, the student should write the equations of the corresponding reactions at home, and immediately write the observations in the lesson after the experiment and draw appropriate conclusions. In the lesson, the student should be ready to answer all the proposed questions on the topic. At the end of each topic are examples of test control cards. For better assimilation of the material at the end of the textbook are reference tables.

# Regulations for Laboratory Work

1. No sooner are the students allowed to start laboratory practical work than they have got acquainted with the Topic of their Laboratory Work, learn the theoretical material using text-books, study-aids, and lectures recordings, have made a brief entry in a laboratory register concerning the contents of experiments and corresponding reaction equations.
2. When in chemistry laboratory, students are allowed to work only with white gowns and caps or kerchiefs on. Every student has at his disposal a permanent workplace which he must keep clean, avoiding jamming it with objects foreign to the referred Work.
3. The student on duty receives devices and reagents necessary for the work of his/her group and places them over the workplaces. Concentrated acids, alkalis, and volatile substances are placed in a hood. It is strictly prohibited to take them out of the hood.
4. Free-flowing reagents must be dispensed with a dry microspatula only. The excess of the substance must not be poured back into the flask where the reagent is stored to prevent the latter from contamination. To avoid confusion, stoppers and covers of bottles with reagents should be closed immediately after the reagents have been taken.
5. On completing the experiments the contents of test tubes should be poured out into the bottle labelled "Discharge of reagents" and placed in a hood.
6. It is strictly prohibited to carry out experiments, which are irrelevant to the referred Laboratory Work.
7. On completing the work every student is to wash the test tubes, hand them over to the person on duty, clean one's workplace, switch off the heating devices, disconnect electric lighting, water, gas, and wash one's hands.

## Safety Regulations

1. All the experiments with poisonous, strongly pungent, volatile substances, concentrated acids and alkalis, as well as heating and calcination, must be carried out exclusively in a hood.
2. Experiments with flammable substances must be carried out as far from the fire as possible.
3. When heating and boiling solutions in a test-tube, fix the latter in a test-tube clamp keeping the orifice away from any other person working beside.
4. Don't bend over the test tubes in which liquid is being heated or boiled, preventing the latter from splashing into your face.
5. To determine the odour of a gaseous substance, slightly wave your hand directing the airflow towards your face and inhale cautiously.
6. Dispense alkali metals and crystalline alkalis using pincers or special tweezers only, with special glasses or mask on.
7. When diluting a concentrated acid, add the latter to water (not otherwise!) by little portions over the glass stick, stirring the solution constantly.
8. In case of fire, switch off all the burners, sand the fire, and cover it with a blanket. If necessary, use a fire extinguisher or call for a fire brigade.

## First Aid

1. Concentrated acid burn. Irrigate the burned area under fast running water, then – with 2% sodium hydrogencarbonate solution. Cover with a sterile dressing wetted with 2-4% potassium permanganate solution.
2. Concentrated alkali solution burn. Irrigate the burned area under fast running water, then – with 1-2% boric or acetic acid solution.
3. Heat burn. First apply a lotion of potassium permanganate or ethyl alcohol solution, then – burn ointment.
4. Acids, alkalis, or other reagents ingress. Wash eyes with a running water, if necessary, call the doctor.
5. Inhaling vapors or gases. In case of poisoning with hydrogen sulphide, chlorine, bromine vapors, nitrogen dioxide, or carbon (II) oxide, help the victim out into the open and send him to the doctor.
6. Every laboratory must be equipped with a first-aid set.
7. At the beginning of semester a teacher gives instructions to every student group as to the observance of safety regulations and regulations for work in a chemistry laboratory. The students acknowledge, with their personal signatures, that they have been acquainted with safety regulations.

# Module I

## LESSON № ___

## Topic: CLASSES AND NOMENCLATURE OF INORGANIC COMPOUNDS

*Theoretical issues*

Simple substances: metals and non-metals. Complex substances: binary, ternary, complex. Oxides and their classification. Simple oxides, dioxides, polymeric, peroxides. Nomenclature of oxides. Basic, acidic, and amphoteric hydroxides. Nomenclature of hydroxides. Acids. Ortho-, meta-, and poly-forms of acids. Dependence of acid-base properties of oxides and hydroxides on the element's position in D. I. Mendeleyev's periodic system and its reduction level. Salts. Salt class determination. Neutral, basic, acidic, double, complex salts. Oxosalts, salt-like compounds. Meta-, ortho- and di-forms of salts. Nomenclature of salts, graphic formulas, physical and chemical properties of the salts. Interaction of salts with acids, bases, metals, and their oxidation-reduction properties.

*Basic concepts*

| | |
|---|---|
| **Oxides** | binary oxygen-containing compounds in which the oxidation state of oxygen is –2. |
| **Hydroxides** | are electrolytes that dissociate with the formation of hydroxide ions $OH^-$ |
| **An Acid** | is a hydrogen-containing compound that, under appropriate conditions, can produce hydrogen ions $H^+$. |
| **An oxoacid** | is an acid containing hydrogen, oxygen, and another nonmetal. |
| **Salts** | are ionic compounds in which hydrogen atoms of acids are replaced by metal ions, or as products of the complete or partial replacement of hydroxide ions in bases with acid residues. |
| **A hydrate** | is a compound in which a certain number of water molecules are associated with each formula unit, for example, $CuSO_4 \cdot 5H_2O$ |

*Home task*

1. Name cation and anion:

| Ion | Name | Ion | Name |
|---|---|---|---|
| $Ca^{2+}$ | | $NH_4^+$ | |
| $PO_4^{3-}$ | | $OH^-$ | |
| $Cl^-$ | | $SO_4^{2-}$ | |
| $CN^-$ | | $Fe^{3+}$ | |
| $CrO_4^{2-}$ | | $NO_3^-$ | |
| $Cr_2O_7^{2-}$ | | $NO_2^-$ | |

6

2. Write equation of the reactions and name the compounds:

| | |
|---|---|
| $H_3PO_4 + KOH \rightarrow$ | $SO_3 + H_2O \rightarrow$ |
| $H_3PO_4 + 2KOH \rightarrow$ | $N_2O_5 + H_2O \rightarrow$ |
| $H_3PO_4 + 3KOH \rightarrow$ | $Na_2O + H_2O \rightarrow$ |

## *Test-questions and problems*

1. Name the compounds:

| | | |
|---|---|---|
| $CuO$ – | $PbO$ – | $N_2O$ – |
| $Cu_2O$ – | $PbO_2$ – | $NO$ – |
| $Al_2O_3$ – | $CdO$ – | $N_2O_3$ – |

2. Define the types of next oxides, fill in the table: $Na_2O$, $CO$, $Al_2O_3$, $ZnO$, $N_2O$, $P_2O_5$, $SiO_2$, $CaO$

| Non-salt forming oxides | Salt forming oxides | | |
|---|---|---|---|
| | basic | acidic | amphoteric |
| | | | |

3. Write the formula of oxides, which are corresponding to hydroxides:

| | |
|---|---|
| $HCl^{+7}O_4 - Cl^{+7}_2O_7$ | $Fe(OH)_3$ – |
| $H_2SiO_3$ – | $H_3BO_3$ – |
| $Cu(OH)_2$ – | $HMnO_4$ – |
| $H_3AsO_4$ – | $H_3PO_4$ – |

4.  Name the acids:

| | | |
|---|---|---|
| HCl – | HClO – | $HPO_3$ – |
| $H_2SO_4$ – | $HClO_2$ – | $H_3PO_4$ – |
| $H_2SO_3$ – | $HClO_3$ – | $H_4P_2O_7$ – |
| $H_2S$ – | $HClO_4$ – | $H_2CO_3$ – |
| $HNO_3$ – | $H_2CrO_4$ – | $CH_3COOH$ – |
| $HNO_2$ – | $H_2Cr_2O_7$ – | $H_3AsO_4$ – |

5.  Write the formulas of acids:

| | |
|---|---|
| Orthophosphoric acid | |
| Metaphosphoric acid | |
| Diphosphoric acid | |

6.  Indicate basicity of the acids:

| | | |
|---|---|---|
| $H_3PO_4$ – | $HMnO_4$ – | $H_5IO_6$ – |
| HCl – | $H_4MnO_4$ – | $H_6TeO_6$ – |
| $H_2SO_4$ – | $H_4P_2O_7$ – | $H_2SiO_3$ – |

7.  Draw the graphic formulas of compounds:

| | | |
|---|---|---|
| $H_2SO_4$ | $Cr(OH)_3$ | $K_3PO_4$ |

8. Write the formulas of compounds, which are, formed the ions. Give the traditional names of compounds:

| Anions | Cations | | |
|---|---|---|---|
| | $NH_4^+$ | $Ca^{2+}$ | $Al^{3+}$ |
| $OH^-$ | | | |
| $Cl^-$ | | | |
| $NO_3^-$ | | | |
| $NO_2^-$ | | | |
| $S^{2-}$ | | | |
| $SO_4^{2-}$ | | | |
| $SO_3^{2-}$ | | | |
| $PO_4^{3-}$ | | | |
| $HPO_4^{2-}$ | | | |
| $H_2PO_4^-$ | | | |
| $CrO_4^{2-}$ | | | |
| $Cr_2O_7^{2-}$ | | | |
| $MnO_4^-$ | | | |

## *The example of control-test*

1. Give definition of notion acidic salts. Give the examples.
2. Write reaction equation of production of aluminium nitrate: $Al(OH)_3 + HNO_3 \rightarrow$
3. Name the following acids: $H_2SO_3$, $H_2SO_4$, $H_2S_2O_7$.
4. Choose the chromium oxide, which possesses the acidic properties: $CrO$, $Cr_2O_3$, $CrO_3$.
5. Draw the graphic formula of calcium carbonate ($CaCO_3$).

# LESSON № ___

## Topic: ATOMIC STRUCTURE

### *Theoretical issues*

Planetary model of atom. Bohr's postulates. Modern quantum mechanical theory of atomic structure. Quantum numbers and their characteristics. Concept of atomic orbitals. Principles and rules determining order of filling atomic orbitals with electrons: least energy principle, Pauli Exclusion Principle, Hund's rule, Klechkovsky's rules. Electron and electron graphic formulae for atoms of elements and their ions.

### *Basic concepts*

| | |
|---|---|
| **An atom** | is an electrically neutral smallest particle of matter that characterizes an element. |
| **An Element** | a set of atoms with the same nuclear charge. |
| **Hund's rule** | states that whenever orbitals of equal energies are available, electron are assigned to these orbitals singly before any pairing of electrons occurs. |
| **The Pauli exclusion principle** | states that no two electrons may have all four quantum numbers alike. This limits occupancy of an orbital to two electrons with opposing spins. |
| **An electron configuration** | is a representation showing the orbital designations of all electrons in an atom. |

### *Home task*

1. Indicate values of main and orbital quantum numbers for the following states of an electron

| States of an electron | Values of quantum numbers | |
|---|---|---|
| | $n$ | $\ell$ |
| 2p | | |
| 4d | | |
| 3s | | |
| 4f | | |

2. Calculate the maximal number of electrons (N) on the following electron sublevels, using the formula $2(2\ell + 1)$:

| Sublevels | Maximal number of electrons |
|---|---|
| s | |
| p | |
| d | |
| f | |

3. Write the electron configurations for the atoms and ions:

| Atoms and ions | Electron configurations | | |
|---|---|---|---|
| $Fe^0$ | $1s^22s^22p^63s^23p^63d^64s^2$ | $KL3s^23p^63d^64s^2$ | [Ne] $3s^23p^63d^64s^2$ |
| $Fe^{2+}$ | | | |
| $Fe^{3+}$ | | | |
| $Al^0$ | | | |
| $Al^{3+}$ | | | |

4. Write electron configurations for sulphur in the compounds:

| Compounds | Oxidation state of sulphur | Electron configurations |
|---|---|---|
| S | | |
| $H_2SO_3$ | | |
| $Na_2SO_4$ | | |
| $K_2S$ | | |

## Test-questions and problems

1. Modern quantum mechanical theory of atomic structure. Quantum numbers. Concept of atomic orbitals.

2. Name the quantum numbers; indicate their values and physical meaning.

| $n$ | $\ell$ |
|---|---|
| | |
| $m$ | $s$ |
| | |

3. Indicate values of quantum numbers for sodium atomic orbital with an outer electron.

| Values of quantum numbers | | | |
|---|---|---|---|
| $n$ | $\ell$ | $m$ | $s$ |
| | | | |

4. Indicate values of main and orbital quantum numbers for the electron sublevels:

| Electron sublevels | Values of quantum numbers | |
|---|---|---|
| | $N$ | $\ell$ |
| $2s$ | | |
| $3d$ | | |
| $4p$ | | |

5. Formulate principles and rules determining order of filling atomic orbitals with electrons

| Pauli exclusion principle | |
|---|---|
| Hund's rule | |
| I$^{st}$ Klechkovsky's rule | 1s<br>2s 2p<br>3s 3p 3d<br>4s 4p 4d 4f<br>5s 5p 5d 5f …<br>6s 6p 6d … … … |
| II$^{nd}$ Klechkovsky's rule | |

6. Determine the order of filling atomic orbitals $3s$, $4s$, $4p$, $3p$, $3d$, $4d$, $5s$ with electrons using Klechkovsky's rules:

| Sublevels | 3s | 4s | 4p | 3p | 3d | 4d | 5s |
|---|---|---|---|---|---|---|---|
| Sum ($n + \ell$) | $3 + 0 = 3$ | | | | | | |
| Order of filling AO | 1 | | | | | | |

7. Write electron and electron graphic formulae for the following atoms:

| H | N |
|---|---|
| Cl | Na |

8. Write electron configurations of the following atoms and ions:

| Atoms | Electron configurations | Ions | Electron configurations |
|---|---|---|---|
| Na | | $Na^+$ | |
| Fe | | $Fe^{2+}$ | |
| P | | $Fe^{3+}$ | |
| Al | | $Al^{3+}$ | |
| Cu | | $Cu^{2+}$ | |
| S | | $S^{2-}$ | |

9. Write electron configurations of chlorine atom in the compounds:

| Compounds | Oxidation state of chlorine | Electron configurations |
|---|---|---|
| $Cl_2$ | | |
| $HClO_3$ | | |
| $HClO_4$ | | |
| $HCl$ | | |

10. Write electron graphic configurations for Sulphur in the normal and exited states.

### *The example of control-test*

1. Indicate the possible values of spin quantum number.
2. Indicate the possible values of magnetic quantum number if the orbital quantum number $\ell$ is equal 2.
3. Indicate the number of electrons on outermost $p$-orbitals of Nitrogen atom.
4. Write electron configurations of Sulphur with the oxidation state –2 in the compound $Na_2S$.
5. Write electron graphic configurations of Sodium atom.

# LESSON № ___

## Topic: D. I. MENDELEEV'S PERIODIC LAW BASED ON THE THEORY OF ATOMIC STRUCTURE

### *Theoretical issues*

History of discovery of the periodic law and creation of the periodic system of elements. Moseley's law, modern formulation of the periodic law. The periodic system of chemical elements as a graphic display of the law of periodicity. The structure of the periodic system. Concepts of periods, rows, groups, subgroups and families. The periodic nature of changing physical (atomic and ionic radii, ionization energy, energy of electron affinity, electronegativity and oxidation state) and chemical properties of simple substances and compounds of elements as a function of electronic structure of atoms.

### *Basic concepts*

| | |
|---|---|
| **An atom** | is an electrically neutral smallest particle of matter that characterizes an element |
| **An Element** | a set of atoms with the same nuclear charge |
| **A group** | is a vertical column of elements with the same number of valence electrons. Members of the group have similar properties |
| **A period** | is a horizontal row of elements in periodic table. All members of a period have atoms with the same highest principal quantum number |
| **The periodic law** | the properties of chemical elements, as well as the shapes and properties of their compounds, are periodically dependent on the magnitude of the charge of the nuclei of their atoms |
| **Atomic radius (orbital)** | theoretically calculated distance of the maximum electron density of the outer electron layer from the nucleus |
| **Ionization energy (ionization potential), I** | is energy needed to detach an electron from a neutral gaseous atom (kJ/mol or eV) |
| **Electron affinity** | energy needed to attach an electron to a neutral unexcited atom (kJ/mol or eV) |
| **Electronegativity** | characteristic of the ability of an atom of an element to attract a common electron pair in a chemical compound. Metals have low electronegativities, nonmetals, high |
| **Isoelectronic** | Species have the same number of electrons (usually in the same configuration). $Na^+$, Ne and $F^-$ are isoelectronic |

### *Home task*

1. Describe the order of changes (increase or decrease) the main properties of the elements and simple compounds in periods and main subgroups with increasing of charges of atomic nuclei. Fill in the tables:

| The main properties of the elements | Atomic radii | Ionization energy (I) | Energy of electron affinity (E) | Electronegativity ($\chi$) | Higher oxidation state |
|---|---|---|---|---|---|
| Along the period | | | | | |
| In the main subgroup | | | | | |

| The main properties of simple compounds | Metallic properties | Non-metal properties | Oxidation activity | Reduction activity |
|---|---|---|---|---|
| Along the period | | | | |
| In the main subgroup | | | | |

2. Write down formulae for oxides and hydroxides of manganese Mn(II), Mn(IV), Mn(VII). Indicate their properties (basic, amphoteric, acidic).

| Compounds | Formulae and properties of oxide | Formulae and properties of hydroxide |
|---|---|---|
| Mn (II) | | |
| Mn (IV) | | |
| Mn (VII) | | |

3. Indicate the electronic families of the following atoms:

| Atom | Electronic families | | | |
|---|---|---|---|---|
| | s | P | d | f |
| Ce | | | | |
| Fe | | | | |
| K | | | | |
| P | | | | |

*Test-questions and problems*

1. Write the modern formulation of the periodic law.

2. Give definitions:

| Period is |
|---|
| Group is |
| Subgroup is |
| Indicate the type of electronic families of elements |

3. Compare the properties of element sulphur and element chromium:

| Properties | S (VIA group element) | Cr (VIB group element) |
|---|---|---|
| Similarities:<br>– electronic configuration | | |
| – number of valence electrons | | |
| – formula of higher oxides and their properties | | |
| – formula of higher hydroxides and their properties | | |
| Distinction:<br>– electronic configuration of valence level | | |
| – properties of simple substances (metal, non-metal) | | |

4. Write the electronic formulas of elements third periods and underline their external (valence) electrons. Do the proper conclusions.

| I group | II group | III group | IV group | V group | VI group | VII group | VIII group |
|---|---|---|---|---|---|---|---|
| Na | Mg | Al | Si | P | S | Cl | Ar |
| | | | | | | | |

Conclusions:

The number of group of the element is equal to     _____

The number of period of the element is equal to     _____

5. Specify the number of group and period of elements K, Al, Cr.

| Element | K | Al | Cr |
|---|---|---|---|
| Electronic configuration | | | |
| Valence electrons and their number | | | |
| Period | | | |
| Group | | | |

6. Write down formulae for higher oxides and hydroxides of elements of the third period and characterize the order of shifting acid-base properties of these compounds with the increasing of nuclear charge of an atom. Do the proper conclusions.

| Element | Na | Mg | Al | Si | P | S | Cl |
|---|---|---|---|---|---|---|---|
| Properties of simple substances (metal, non-metal) | | | | | | | |
| Formulae of higher oxides | | | | | | | |
| Properties of oxides (acidic, basic amphoteric) | | | | | | | |
| Formulae of higher hydroxides | | | | | | | |
| Properties of hydroxides (acidic, basic amphoteric) | | | | | | | |

Conclusion: along the period with the increasing of nuclear charge of an atom the properties of oxides and hydroxides change from _____ through _____ to _____.

7. Write down formulae for higher oxides and hydroxides of IV A group elements and characterize the order of shifting acid-base properties of these compounds with the increasing of nuclear charge of an atom. Do the proper conclusions.

| Element | C | Si | Ge | Sn | Pb |
|---|---|---|---|---|---|
| Properties of simple substances (metal, non-metal) | | | | | |
| Formula of higher oxides and their properties | | | | | |
| Formula of higher hydroxides and their properties | | | | | |

Conclusion: along the period with the increasing of nuclear charge of an atom the properties of oxides and hydroxides change from _____ through _____ to _____.

8. Arrange the following elements in the expected order of increasing size of atom:

| **Elements of the third period** | Si, Na, P, S | |
|---|---|---|
| **Elements II A group** | Ba, Mg, Ca, Be | |

9. Arrange the following elements in the expected order of increasing of ionization energy (table 3):

| Elements of the third period | P, Na, Si, Al | |
|---|---|---|
| Elements VA group | Sb, N, As, P | |

10. Arrange the following elements in the expected order of increasing of electron affinity (table 3).

| Elements of the second period | N, F, B, C | |
|---|---|---|
| Elements VIIA group | I, F, Br, Cl | |

11. Arrange the following elements in the expected order of increasing of electronegativity (table 4).

| Elements of the second period | Li, F, O, N | |
|---|---|---|
| Elements VII A group | I, Cl, F, Br | |

### *The example of control-test*

1. Give definition of ionization energy. Specify its units of measuring and character of changing in a period and group.
2. Give definition Moseley's law and write its mathematical expression.
3. Write symbol for element, ion of which are corresponding to the following electron formulae: $E^{3+}$ $1s^22s^22p^63s^2$.
4. Explain the order of changes of acidic properties of hydroxides: $H_2CO_3 - H_2SiO_3 - Sn(OH)_2 - Pb(OH)_2$.
5. Write down electron formulae of Sulphur atom in the compound $Na_2S$.

# LESSON № ___

## Topic: CHEMICAL BOND AND STRUCTURE OF MOLECULES

### *Theoretical issues*

Modern concepts of the nature of a chemical bond. Types of chemical bonds. Parameters of a chemical bond.

Covalent bond. Method of valence bonds (VB). Exchange and donor-acceptor mechanisms of covalent bonds formation. Properties of a covalent bond: saturability, orientation, polarizability. Formation of bonds in an excited state atom. Spatial configuration of molecules. Hybridizations of valence orbitals of a central atom. Valence. Covalent-polar bond. Dipole moment of molecules and its units. Drawbacks of VB method. Ionic bond. Metallic bond. Intermolecular interaction (orientation, induction, dispersion). Hydrogen bond. Role of a hydrogen bond in biological systems.

### *Basic concepts*

| | |
|---|---|
| **A covalent bond** | is a results from the sharing of electrons between atoms |
| **A saturability** | this is the ability of atoms to form a limited number of covalent bonds |
| **A chemical bonding direction** | determines the spatial configuration of the molecule |
| **Dipole moment ($\mu$)** | is a measure of the extent to which a separation of charges exists within a molecule. It is the product of the magnitude of the charge and the distance spear |
| **An ionic bond** | is a results from the transfer of electrons between metal and nonmetal atoms. Positive and negative ions are formed and held together by electrostatic attraction |
| **A metallic bond** | is a type of chemical bond formed between positively charged atoms in which the free electrons are shared among a lattice of cations |
| **A hydrogen bond** | bond between a hydrogen atom that is bonded to a more electronegative atom and another electronegative atom |
| **A valence** | this is the number of covalent bonds formed by an atom of an element in the ground or excited state by the exchange and donor-acceptor mechanisms. Or is this the number of valence level orbitals involved in the formation of chemical bonds |
| **Oxidation state** | atomic charge, which is calculated on the assumption that the molecule is neutral and consists of ions |
| **Bond distance** | is the distance between the nuclei of atoms joined by a chemical bond |

### *Home task*

Fill in the table:

| | $N_2$ | | CO | |
|---|---|---|---|---|
| **Electronic configuration** | N | | C | |
| **Electron-graphic configuration of valence electrons** | N | | C | O |
| **Type of bond (table 4)** | $\Delta\chi =$ <br> type of bond – | | $\Delta\chi =$ <br> type of bond – | |
| **Structural formula** | | | | |

*Test-questions and problems*

| 1. Types of chemical bond are: | 2. Parameters of chemical bond are: | 3. Properties of covalent bond on the base of VB method are: |
|---|---|---|
| | | |

4. Fill in the table (use Table 4):

| Compounds | $\Delta\chi$ | Type of bond |
|---|---|---|
| $H_2$ | $\Delta\chi(H–H) = \chi(H) – \chi(H) = 2.1 – 2.1 = 0$ | Covalent nonpolar bond |
| $CaH_2$ | | |
| $SiCl_4$ | | |
| $HCl$ | | |
| $NH_3$ | | |
| $NaF$ | | |
| $H_2S$ | | |

5. Using VB method explain the mechanism of bonds formation in a molecule $H_2$:

6. Using VB method explain the mechanism of bonds formation in a molecule $BF_3$. Taking into account the concept of donor-acceptor mechanism of covalent bonds formation, explain the formation of $BF_4^-$ ion.

7. Determine the type of chemical bonds in the molecule $NaHSO_4$
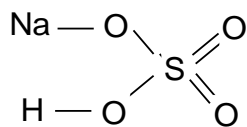
| | Δχ | Type of bond |
|---|---|---|
| | | |
| $\Delta\chi_{Na-O} =$ | | |
| $\Delta\chi_{S-O} =$ | | |
| $\Delta\chi_{H-O} =$ | | |

Na — O
H — O
O
O
S

8. Fill in the table:

| Compounds | Box diagrams of elements | | Electron – dot diagram of bonding | Type of hybridization | Geometry of molecule and valence corner |
|---|---|---|---|---|---|
| | normal state | excited state | | | |
| $BeCl_2$ | Be | Be* | | | |
| $BCl_3$ | B | B* | | | |
| $BF_4^-$ | B | B* | | | |
| $CH_4$ | C | C* | | | |
| $NH_3$ | N | N* | | | |
| $H_2O$ | O | O* | | | |

9. Fill in the table:

| Ionic bond is | |
|---|---|
| Properties of ionic bond are | |
| The example of compounds | |

10. Fill in the table:

| Metallic bond is | |
|---|---|
| Properties of metallic bond are | |

11. Fill in the table:

| Hydrogen bond is | |
|---|---|
| Properties of hydrogen bond | |
| Properties of hydrogen bond | |
| The example of compounds. Indicate the hydrogen bond with three dots. | |

12. Describe the different types of intermolecular interaction

## *The example of control-test*

1. Give the definition of chemical bond and name the types of chemical bond.
2. On the bases of the electronegativity values indicate the type of chemical bond in the molecule: $O_2$, $SO_2$, KCl.
3. Explain the mechanism of bonds formation in a molecule $NH_3$. Taking into account the concept of donor-acceptor mechanism of covalent bonds formation, explain the formation of $NH_4^+$ ion.
4. Determine the type of AO hybridization of boron atom in molecule $BCl_3$. Indicate the spatial structures of these molecules and valence corner.
5. Specify the electrons of oxygen, which take part in formation of the bond (valence electrons) in a molecule CO and define valence of oxygen.

# LESSON № ___

## Topic: CHEMICAL KINETICS AND CHEMICAL EQUILIBRIUM. CATALYSIS

### *Theoretical Issues*

Chemical kinetics. Homogeneous and heterogeneous reactions. Average and instantaneous rates of reactions. Factors influencing the rate of chemical reactions. Dependence of the rate of a chemical reaction on the concentration. The law of acting masses. Rate constant and its physical meaning. Order and molecularity of chemical reactions. Temperature effect on the chemical reaction rate. Van't Hoff Law. Dependence of activation energy on the nature of reacting substances.

Reversible and non-reversible chemical reactions. Chemical equilibrium. Chemical equilibrium constant. Chemical equilibrium shifting. Le Chatelier's principle.

Catalysis. Catalysts. Mechanisms of catalysis. Energy of activation of catalytic reactions. Homogenous and heterogeneous catalysis. Inhibitors. Enzymes.

### *Basic concepts*

| | |
|---|---|
| **The rate of a chemical reaction** | is related to how fast reactants are consumed or products are formed |
| **Homogeneous reactions** | any of a class of chemical reactions that occur in a single phase (gaseous, liquid, or solid) |
| **Heterogeneous reactions** | any of a class of chemical reactions in which the reactants are components of two or more phases (solid and gas, solid and liquid, two immiscible liquids) or in which one or more reactants undergo chemical change at an interface, e.g., on the surface of a solid catalyst |
| **The rate law** | for a reaction relates the reaction rate the concentrations of reactants. It has the form: reaction rate $V = kc^m(A) \times c^n(B)$ |
| **An activated complex** | is an intermediate species in the mechanism of a chemical reaction |
| **Exothermic reactions** | occur with the release of heat ($\Delta H < 0$) |
| **Endothermic reactions** | occur with heat absorption ($\Delta H > 0$) |
| **Activation energy** | the minimum energy a molecule needs to have to undergo a reaction |
| **Irreversible chemical reactions** | reactions, as a result of which the reagents are completely converted into products |
| **Reversible chemical reactions** | reactions that simultaneously occur in opposite directions |
| **Chemical equilibrium** | dynamic state of the system at which the rates of forward and reverse reactions are the same |
| **Le Chatelier's principle** | a principle stating that if a constraint (such as a change in pressure, temperature, or concentration of a reactant) is applied to a system in equilibrium, the equilibrium will shift so as to tend to counteract the effect of the constraint |
| **Catalysts** | substances that change the rate of a chemical reaction, but themselves remain as a result of the reaction |
| **Catalysis** | is the speeding up of a reaction in the presence of an agent(catalyst) that changes the reaction mechanism to one of lower activation energy |
| **Enzymes** | biological catalysts |
| **Van't Goff Rule** | with an increase in temperature for every 10 °C, the rate of most chemical reactions increases 2 – 4 times |
| **Equilibrium constant** | ratio of the rate constants of direct and reverse reactions |

*Home task*

For the following reaction $4HCl_{(g)} + O_{2(g)} \leftrightarrows 2Cl_{2(g)} + 2H_2O_{(g)}$; $\Delta H > 0$:

a) fill in the table:

| The rate of forward reaction | The rate of reverse reaction | Equilibrium constant |
|---|---|---|
| $V_{for.} =$ | $V_{rev.} =$ | $K =$ |

b) indicate (line) factors which increase the speed of reaction of $Cl_2$ production:
   – increasing of concentration of HCl
   – heating
   – increasing of concentration of $H_2O$
   – increasing of pressure
   – decreasing of concentration of $O_2$

*Test-questions and problems*

1. Give definition and write the examples of homogeneous and heterogeneous reactions. Fill in the table:

| Reaction equations | Type of the reaction (homogenous and heterogeneous ) | Rate of the forward reaction |
|---|---|---|
| $H_{2(g)} + Cl_{2(g)} \leftrightarrows 2HCl_{(g)}$ | homogenous | $V_{for.} = kc(H_2) \times c(Cl_2)$ |
| $2NO_{(г)} + O_{2(г)} \leftrightarrows 2NO_{2(g)}$ | | $V_{for.} =$ |
| $CaO_{(s)} + CO_{2(g)} \leftrightarrows CaCO_{3(s)}$ | | $V_{for.} =$ |
| $4NH_{3(g)} + 3O_{2(g)} \leftrightarrows 2N_{2(g)} + 6H_2O_{(g)}$ | | $V_{for.} =$ |
| $FeO_{(s)} + H_{2(g)} \leftrightarrows Fe_{(s)} + H_2O_{(g)}$ | | $V_{for.} =$ |

2. Write the equilibrium constant expression:

| Reaction equation | Equilibrium constant |
|---|---|
| $2CO_{(g)} + O_{2(g)} \leftrightharpoons 2CO_{2\ (g)}$ | $K = \dfrac{[CO_2]^2}{[CO]^2[O_2]}$ |
| $MgCO_{3(s)} \leftrightharpoons MgO_{(s)} + CO_{2(g)}$ | $K =$ |
| $N_{2(g)} + O_{2(g)} \leftrightharpoons 2NO_{(g)}$ | $K =$ |
| $3Fe_{(s)} + 4H_2O_{(g)} \leftrightharpoons Fe_3O_{4(s)} + 4H_{2(g)}$ | $K =$ |
| $NH_{3(g)} + HCl_{(g)} \leftrightharpoons NH_4Cl_{(s)}$ | $K =$ |

3. How the speed of direct reaction will change, if the volume of gas mixture will be increased in three times?
   The volume will increase 3 times, and the concentration will decrease 3 times.

| | | | |
|---|---|---|---|
| $CO_{(g)} + Cl_{2(g)} \leftrightharpoons COCl_{2(g)}$ | $V_{forward} = kc(CO) \times c(Cl_2)$ | $V'_{forward} = k1/3c(CO) \times 1/3c(Cl_2)$ | $\dfrac{V_{for}}{V'_{for}} = 9$ |
| $2SO_{2(g)} + O_{2(g)} \leftrightharpoons 2SO_{3(g)}$ | | | $\dfrac{V_{for}}{V'_{for}} =$ |
| $N_{2(g)} + 3H_{2(g)} \leftrightharpoons 2NH_{3(g)}$ | | | $\dfrac{V_{for}}{V'_{for}} =$ |

4. The temperature coefficient ($\gamma$) is equal 2. How the speed of the reaction will change if the temperature will be increased from 60 to 90 ºC?
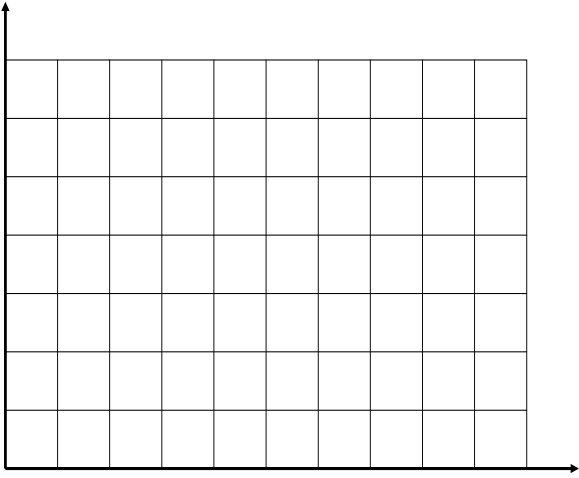
5. Using principle of Le Châtelier, determine the direction of shifting of equilibrium of reaction:

| Reaction | Increasing of pressure | Increasing of the concentration of reactants | Increasing of temperature |
|---|---|---|---|
| $N_{2(g)} + 3H_{2(g)} \leftrightarrows 2NH_{3(g)} + Q$ ($\Delta H < 0$) | $\rightarrow$ | $\rightarrow$ | $\leftarrow$ |
| $2HI_{(g)} \leftrightarrows H_{2(g)} + I_{2(g)} - Q$ ($\Delta H > 0$) | | | |
| $2NO_{(g)} \leftrightarrows N_{2(g)} + O_{2(g)} + Q$ ($\Delta H < 0$) | | | |
| $2H_2S_{(g)} \leftrightarrows 2H_{2(g)} + 2S_{(g)} - Q$ ($\Delta H > 0$) | | | |
| $2SO_{2(g)} + O_{2(g)} \leftrightarrows 2SO_{3(g)} + Q$ ($\Delta H < 0$) | | | |

## *The example of control-test*

1. Write down mathematical expressions of average reaction rates.
2. Write down reverse reactions rate expression: $MgCO_{3(s)} \leftrightarrows MgO_{(s)} + CO_{2(g)}$.
3. Indicate the direction of shifting of equilibrium of the reaction at the increasing of pressure: $N_{2(g)} + O_{2(g)} \leftrightarrows 2NO_{(g)}$.
4. Write down expression of constant of chemical equilibrium for a reaction: $CO_{2(g)} + H_{2(g)} \leftrightarrows CO_{(g)} + H_2O_{(g)}$.
5. Under the equilibrium of the following reaction: $4HCl + O_2 \leftrightarrows 2Cl_2 + 2H_2O$ the concentration of hydrogen chloride is 0.1 mol/L; of oxygen 0.05 mol/L; chlorine 0.9 mol/L; steams of water 0.9 mol/L. Determine the constant of equilibrium.

*Laboratory Work*

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | | | Conclusions |
|---|---|---|---|---|---|
| **Experiment 1.**<br><br>**Dependence of the rate of a chemical reaction on the concentration**<br><br>    Prepare three sodium thiosulphate solutions of different concentrations. Place four drops of 0.01 *M* sodium thiosulphate solution and eight drops of water in a dry test-tube 1. Place eight drops of 0.01 *M* sodium thiosulphate solution and four drops of water in test-tube 2. Fill test-tube 3 with twelve drops of 0.01 *M* sodium thiosulphate solution. Add one drop of 2 *N* solution of sulphuric acid to test-tube 1. Using a stop-watch, note the interval between the addition of the acid and the time when the solution is turning noticeably opalescent. Carry out the same experiments with test-tubes 2 and 3. Fill in the table. Draw up the graphic chart of the reaction rate dependence on the concentration of the reacting substances. Plot on the abscissa axis sodium thiosulphate concentrations, and on the axis of ordinates – rates corresponding to them, expressed in relative units<br><br>$$V = \frac{1}{\tau}, \text{s}^{-1}$$<br><br>where $\tau$ – time interval of reaction.<br>    Draw a conclusion as to the reaction rate dependence on the concentration. | | $Na_2SO_3S + H_2SO_4 \rightarrow$ | | | |

Table in "Chemical reaction equations" column:

| № | Concentration $Na_2S_2O_3$, relative units | Reaction time interval, s | $V = \frac{1}{\tau}$, s⁻¹ |
|---|---|---|---|
| 1 | 1/3 | | |
| 2 | 2/3 | | |
| 3 | 1 | | |

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 2.**<br>**Catalytic effect on chemical reaction rate**<br>Introduce three-five drops of 3% hydrogen peroxide solution into each of two test tubes. Add several crystals of manganese (IV) oxide to test-tube 1. Write down the hydrogen peroxide decomposition reaction. Indicate the role of manganese (IV) oxide in the hydrogen peroxide decomposition reaction and name the type of the catalyst. | | $H_2O_2 \xrightarrow{MnO_2}$ | |
| Experiment 3.<br>Reagents concentration effect<br>on chemical equilibrium<br>Place five-seven drops of 0.0025 $N$ iron (III) chloride solution into each of 4 test tubes and add five-seven drops of 0.0025 $N$ potassium thiocyanate solution to each of them. Stir the contents of test tubes with a glass stick. Leave the first one for future comparison (as a control test-tube). Add one drop of saturated iron (III) chloride to test-tube 2, to test-tube 3 – one drop of saturated potassium thiocyanate solution, to test-tube 4 – several crystals of potassium chloride.<br>Compare the intensity of solutions coloration to that of the solution in the control test-tube. Write down the equation for the reversible reaction and the equilibrium constant expression. Fill in the table. | | FeCl$_3$ + KSCN $\rightarrow$<br><br><br>$K =$ | |

| Test-tube № | Solution coloration intensity on addition of | | | Direction of equilibrium shifting |
|---|---|---|---|---|
| | FeCl$_3$ saturated solution | KSCN saturated solution | KCl crystals | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| control | | | | |

# LESSON № ___

## Topic: SOLUTIONS. QUANTITATIVE COMPOSITION EXPRESSION METHODS OF SOLUTIONS

### *Theoretical issues*

Solutions. Solvent, solute. D. I. Mendeleev's chemical theory of solutions. Modern theory of solutions. Calorific effect of solution process. The phenomenon of solvation (aquation). Solubility. Solubility of gases in liquids. Solubility of liquids and solids in water. Solubility curves. Concentrated and diluted solutions. Saturated and supersaturated solutions. Ways of solution concentration expressing. Solution concentration: percent, by mass, of a substance in a solution; molar concentration; molar concentration of equivalent (normal concentration); molal concentration; titer. Solutions in chemical practice and biological processes.

### *Basic concepts*

| | |
|---|---|
| **Solutions** | is a special type of homogeneous mixture composed of two or more substances. |
| **The solvent** | is the solution component present in greatest quantity |
| **A solute(s)** | is (are) the solution component(s) present in lesser amount(s) than the solvent |
| **A saturated solution** | is one that contains the maximum quantity of solute that is normally possible |
| **Supersaturated solution** | contains, because of its manner of preparation, more solute than normally expected |
| **Mass percent, $\omega(B)$** | mass of solute in 100 g of solution (fractions of a unit or in %). |
| **Molar concentration, $c(B)$** | the amount of solute in 1 liter of solution (mol/L) |
| **Molar equivalent concentration, (Normality) $c_{equiv}$** | the number of mol equivalents of solute in 1 liter of solution (mol equivalents /L) |
| **Molality, $c_m$** | is a solution concentration expressed as number of moles of solute per kilogram of solvent |
| **Titer, T** | mass of solute in 1 mL of solution (g / mL ) |

### *Home task*

1. Fill in the table:

| Type of concentrations | Definition | Formula for calculation | Units |
|---|---|---|---|
| Mass percent | | | |
| Molar concentration | | | |
| Molar concentration of equivalent | | | |
| Molal concentration | | | |
| Titer | | | |

2. Write an expression to calculate the equivalent mass of the compounds:

| a) acids | b) bases | c) salts |
|---|---|---|
| $HCl$,  $H_2SO_4$,  $H_3PO_4$ | $NaOH$  $Ba(OH)_2$ | $NaCl$  $Na_2CO_3$  $NaHCO_3$ |

## *Test-questions and problems*

1. Fill in the table:

| **Solution is** | |
|---|---|
| **Component of solution are** | |
| **According to aggregate states the solutions are** | |

2. Fill in the table:

| **Solubility of the substances is** | |
|---|---|
| **Coefficient of solubility is** | |
| **"Like dissolves like" is mean** | |

3. Explain the following species:

| **Concentrated solution is** | |
|---|---|
| **Diluted solution is** | |
| **Unsaturated solution is** | |
| **Saturated solution is** | |
| **Supersaturated solution is** | |

4. Calculate concentration of NaCl. Fill in the table:

| | Mas percent, $\omega$ | Molar concentration, $c(B)$ | Molar concentration of equivalent, $c_{equiv}$ | Molal concentration, $c_m$ | Titer, T |
|---|---|---|---|---|---|
| m NaCl = 3 g<br>m $H_2O$ = 97g<br>$\rho_{solution}$ = 1.02 g/mL | | | | | |

5. Give the definition of heating effect of dissolution for solid substance.


Determine exo- or endothermic will be a process of dissolution of matter, if $\Delta H_{solvatation} > \Delta H_{bond}$.


6. Calculate mass of potassium iodide KI for preparation of 300 g of 10 % solution.

| m solution = 300 g |
|---|
| $\omega$ = 10 % |
| m (KI) – ? |

7. Calculate mass of sulfuric acid $H_2SO_4$ (M $H_2SO_4$ = 98 g/mol) for preparation of 2 L of 0.1 M solution.

| V solution = 2 L |
|---|
| c = 0.1 mol/L |
| M $H_2SO_4$ = 98 g/mol |
| m $H_2SO_4$ – ? |

8. Calculate molar concentration of equivalent of sulfuric acid $H_2SO_4$, if 300 mL of solution contains 4.9 g of solute.

| m $H_2SO_4$ = 4.9 g |
|---|
| V solution $H_2SO_4$ = 300 mL |
| M $H_2SO_4$ = 98 g/mol |
| $c_{equiv}$ – ? |

9. Calculate molar concentration of equivalent $c_{equiv}$ of sodium hydroxide solution if 50 mL of this solution is used for neutralization of 25 mL 0.25 $N$ solution of sulphuric acid.

*Laboratory Work*

| Appellation and brief description of the experiment | Calculations | Conclusions |
|---|---|---|
| **Preparing solutions of given percent, by mass, through mixing of two solutions**<br><br>Adding 20% sodium chloride solution, by mass, to 100 mL of 3% sodium chloride solution, by mass, produce solution with 8% or 10% mass proportion (follow teacher's instructions).<br>For calculations use the dates of density of solutions (table 2).<br>Using an aerometer determine the density of the prepared solution and compare it to the data from the table. By the density of the solution produced, calculate it's percent, by mass, as well as molar, normal, molal concentrations and solution titer. | | |

*The example of control-test*

1. What is the titer of the solution?
2. Calculate the molarity of a solution prepared by dissolving 11.5 g of solid sodium hydroxide in enough water to make 1.50 L of solution.
3. Calculate the volume of 0.1 $N$ nitric acid solution needed to neutralize 125 mL of 0.05 $N$ potassium hydroxide.
4. Calculate mass of sodium chloride needed for preparation of 300g 10% solution.
5. Calculate titer of potassium chloride solution if 1 L of this solution contain 15 g of solute.

# LESSON № ___

## Topic: ELECTROLYTIC DISSOCIATION

### *Theoretical issues*

Electrolytes and non-electrolytes. Theory of electrolytic dissociation. Strong and weak electrolytes. Equilibrium in solutions of weak electrolytes. Degree and constant of dissociation. Shifting of ionic equilibrium in solutions of weak electrolytes. Ostwald's dilution law. Acids, bases, and salts according to the theory of electrolytic dissociation.

Shifting equilibrium of reaction of weak electrolyte dissociation. Ionic reactions. Water dissociation. Ionic water product (Kw). Index to "potential of hydrogen", pH values of acids and bases. Equilibrium in solutions of slightly soluble electrolytes. Solubility and solubility product.

### *Basic concepts*

| | |
|---|---|
| **Electrolytic dissociation** | in electrolytic, or ionic, dissociation, the addition of a solvent or of energy in the form of heat causes molecules or crystals of the substance to break up into ions (electrically charged particles) |
| **Electrolytes** | are substances whose solutions or melts conduct electric current |
| A **strong electrolyte** | is a substance that exists completely in the form of ions in solutions |
| A **weak electrolyte** | is a substance that is present in solution partly in molecular form and partly as ions |
| **Non-electrolytes** ($\alpha = 0$) | are substances whose solutions or melts do not conduct electric current |
| **Ampholytes** | substances that, depending on the conditions, are capable of dissociating as an acid (with the formation of $H^+$) or a base (with the formation of $OH^-$) |
| **Degree of dissociation** ($\alpha$) | the ratio of the number of electrolyte molecules disintegrated into ions in an aqueous solution to the total number of dissolved molecules (fractions of a unit or %) |
| **Dissociation constant** ($K_d$) | equilibrium constant of the dissociation process |
| **Ostwald's dilution law** | the degree of dissociation is determined by the dissociation constant and the concentration of weak electrolyte in the solution. $\alpha = \sqrt{\dfrac{K_d}{c}}$ |
| **Ionic product of water** ($K_W$) | the product of concentrations of $H^+$ and $OH^-$ions in water at a particular temperature. Since pure water is neutral in nature, $H^+$ ion concentration must be equal to $OH^-$ ion concentration. ($K_W = [H^+][OH^-] = 10^{-14}$ at 25 °C) |
| **Hydrogen indicator** (pH) | the decimal logarithm of the concentration of hydrogen ions with a minus sign: pH = $-\log[H^+]$, medium neutral pH = 7, acidic pH < 7, alkaline pH > 7 |
| **Solubility product**,($K_{sp}$) | is the equilibrium constant for a chemical reaction in which a solid ionic compound dissolves to yield its ions in solution |

## Home task

1. Write equations of dissociation in diluted solution of electrolyte. Fill in the table:

| Formula of compounds | Type of electrolyte | Equations of dissociation | Value of degree of dissociation ($\alpha$) | Expression of constant $K_i$ |
|---|---|---|---|---|
| NaOH | alkali | $NaOH \rightarrow Na^+ + OH^-$ | $\alpha > 30\,\%$ | – |
| NH₄OH | weak base | $NH_4OH \leftrightarrows NH_4^+ + OH^-$ | $\alpha < 3\,\%$ | $K_i = \dfrac{[NH_4^+][OH^-]}{[NH_4OH]}$ |
| Mg(OH)₂ | weak base | | $\alpha < 3\,\%$ | $K_{i\ gen} =$ |
| HCl | strong acid | | $\alpha > 30\,\%$ | – |
| CH₃COOH | weak acid | | $\alpha < 3\,\%$ | |
| H₂S | weak acid | | $\alpha < 3\,\%$ | $K_{i\ gen} =$ |
| NaCl | mean salt | | $\alpha > 30\,\%$ | – |

2. Calculate concentration of cation of hydrogen in 0.001 $M$ solution of sulphuric acid.

3. Calculate concentration of hydroxide ions in 0.05 $M$ solution of barium hydroxide Ba(OH)₂.

4. Indicate the direction of equilibrium shifting of reaction of weak electrolyte dissociation $CH_3COOH \leftrightarrows CH_3COO^- + H^+$ under the following conditions:

| The conditions | Direction of shifting |
|---|---|
| Increase $c(CH_3COOH)$ | ← |
| Increase $c(H^+)$ | |
| Increase $c(OH^-)$ | |
| Decrease $c(CH_3COOH)$ | |
| Addition of HCl | |
| Addition of $Na_2CO_3$ | |

*Test-questions and problems*

1. Electrolytes are the compounds _____

_____

| | Strong electrolytes | Weak electrolytes |
|---|---|---|
| **Examples** | | |

2. Write equation of dissociation of weak electrolyte HCN and the expression of constant ionization $K_a$.

3. Write equations of step dissociation of carbonic acid and expressions of step and general dissociation constants (see table 6 to indicate values of $K_{a1}$ and $K_{a2}$ of carbonic acid).

4. Write expression of Ostwald's dilution law. Calculate degree of dissociation for solution of acetic acid with different concentration. Fill in the table:

| Molar concentration | | |
|---|---|---|
| $c_1 = 1$ mol/L | $\alpha = \sqrt{\dfrac{K_d}{c}}$ | $\alpha_1 =$ |
| $c_2 = 0.1$ mol/L | | $\alpha_2 =$ |
| $c_3 = 0.01$ mol/L | | $\alpha_3 =$ |

Conclusion: Degree of dissociation of weak electrolyte at denomination of its concentration _____

5. Water as an electrolyte. The pH scale.

6. Calculate pH of 0.05 $M$ solution of sulphuric acid.

7. Calculate pH of 0.1 $M$ solution of nitrous acid $HNO_2$. $K_a$ $HNO_2 = 4.0 \times 10^{-4}$.

8. Solubility is _____

_____

9. Fill in the table

| Compounds | Reaction of dissociation | Expression of solubility product | Formula for the calculation of solubility |
|---|---|---|---|
| AgCl | $AgCl \leftrightarrows Ag^+ + Cl^-$ | $K_{SP} = [Ag^+] \times [Cl^-] = S^2$ | $S = \sqrt{K_{SP}}$ |
| Fe(OH)$_2$ | | | |

10. Using the solubility products of iron (II) sulphide (Table 7) and the value of general constant of dissociation of hydrosulphuric acid (Table 6, $K_{i\ gen} = K_{i1} \times K_{i2}$), explain the solubility of the precipitates of iron (II) sulphide in hydrochloric acid. Write down the equations.

$FeS_{(s)} + HCl_{(aq)} \leftrightarrows$

# LESSON № ___

## Topic: ELECTROLYTIC DISSOCIATION

*Home task*

1. Calculate pH 0.005 $M$ of solution of barium hydroxide.

2. Write down the expression of silver chloride solubility product. Indicate the conditions of formation and dissolving of AgCl precipitate.

3. Calculate the solubility of $Fe(OH)_2$ at 25 ºC in the unit mole/L. $K_{SP}$ $Fe(OH)_2 = 1 \times 10^{-15}$.

4. Solubility product of silver iodide at 25 ºC is equal $1.1 \times 10^{-16}$. Calculate concentration of cation of silver in the saturated solution.

5. Solubility of barium sulfate at 25 ºC is equal $1.05 \times 10^{-5}$ mol/L. Calculate $K_{SP}$ $BaSO_4$.

*Laboratory Work*

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 1.** <br> **Shifting equilibrium of reaction** <br> **of weak electrolyte dissociation** <br><br> a) Introduce four-five drops of 0.1 *N* acetic acid solution ($CH_3COOH$) to each of two test tubes. Add one drop of methyl-orange to each of them. Leave the first one for future comparison (as a control test-tube), and add a microspatula of crystalline sodium acetate ($NaCH_3COO$) to the second one. Stir the solution with a glass stick. Compare the resulting solution colour to that of the solution in the control test-tube. Explain what caused shift of acetic acid dissociation equilibrium. Write down the equations for acetic acid and sodium acetate dissociation reactions. | | | |
| b) Introduce four-five drops of 0.1 *N* ammonium hydrate solution to each of two test tubes. Add one drop of phenolphthalein to each of them. Leave the first one for future comparison (as a control test-tube), and to the second one add a microspatula of crystalline ammonium chloride. Stir the solution with a glass stick. Compare the resulting solution colour to that of the solution in the control test-tube. Explain what caused the shift in ammonium hydrate dissociation reaction equilibrium. Write down the equations for ammonium hydrate and ammonium chloride dissociation reactions. | | | |

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 2. Ionic reactions**<br>a) Introduce two-three drops of 0.5 *N* iron (III) chloride solution to each of two test tubes. Then, add two-three drops of 2 *N* sodium hydroxide solution to test-tube 1 and three drops of saturated calcium hydroxide solution to test-tube 2. Note the colours and the quantities of precipitates. Write down molecular and abbreviated ionic reaction equations. | | | |
| b) Place two-three drops of 0.5 *N* sodium carbonate solution to each of two test-tube, then add to test-tube 1 three-four drops of 2 *N* hydrochloric acid solution, and to test-tube 2 – three-four drops of acetic acid. Notice the intensity of gassing. Write down the molecular and abbreviated ionic reaction equations. | | | |
| **Experiment 3. Conditions of a precipitate resolution resulting from chemical interaction**<br>Transfer two-three drops of 0.5 *N* copper (II) sulphate solution to the first of two test tubes, and to the second one – two-three drops of 0.5 *N* iron (II) sulphate solution. Add four-five drops of 0.5 *N* sodium sulphide solution to each of them. Notice the colour of the resulting solutions. Add four-five drops of 2 *N* hydrochloric acid solution to the precipitates formed. Using the solubility products ($K_{SP}$) of iron (II) sulphide and copper (II) sulphide (Table 7), as well as the value of general $K_a$ of hydrosulphuric acid (Table 6), explain the solubility of the precipitates in hydrochloric acid. Write down corresponding molecular and abbreviated ionic reaction equations. | | | |

## *The example of control-test*

1. Give examples of bases, which are strong electrolytes.
2. List the factors that affect the value of the dissociation constant.
3. Write the molecular and ionic equations: $Na_2CO_3 + H_2SO_4 = Na_2SO_4 + H_2O + CO_2$
4. Calculate the concentration of hydroxide ions and pH of 0.01 *M* sodium hydroxide solution.
5. The solubility of iron (II) hydroxide at 25 ºC is $1.0 \times 10^{-15}$. Calculate the solubility product of $Fe(OH)_2$.

# LESSON № ___

## Topic: SALTS HYDROLYSIS

### *Theoretical issues*

The concept of hydrolysis. The cause and mechanism of salt hydrolysis. Salt hydrolysis as a reversible process: hydrolysis degree and hydrolysis constant. Factors determining hydrolysis degree and hydrolysis constant. Hydrolysis of acidic salts and assessment of acidity of medium of their solutions. Characters of antimony (III), bismuth (III), and tin (IV) salts hydrolysis. Effect of dilution, same ions concentration increase, hydrogen cations, and hydroxide ions on the direction of shift in hydrolysis equilibrium. Co-hydrolysis of salts. Hydrolysis of compounds with covalent bonds. Significance of hydrolysis for biological systems and pharmaceutical practice.

### *Basic concepts*

| | |
|---|---|
| **Hydrolysis of salts** | interaction with water leads to the formation of a weak electrolyte and a change in pH. |
| **Degree of hydrolysis** (h) | degree of Hydrolysis is defined as the fraction of the salt which is hydrolyzed at equilibrium. For example, if 90% of salt solution is hydrolyses is 0.9 or as 90%. |
| **The degree of hydrolysis is affected** | salt nature, concentration, temperature |
| **Hydrolysis constant** ($K_h$) | A hydrolysis constant is an equilibrium constant for a hydrolysis reaction. |
| **Ostwald dilution law for hydrolysis of salts** | upon dilution of the salt solution, the degree of its hydrolysis increases |

### *Home task*

1. Write the equation of dissociation in dilute solutions of electrolytes. Fill in the table:

| Formula of salt | Ionic and molecular equations of hydrolysis reaction | Acidity of medium | Expression of $K_h$ |
|---|---|---|---|
| $K_2CO_3$<br>salt of weak two-base acid | $CO_3^{2-} + HOH \leftrightarrows HCO_3^- + OH^-$<br>$K_2CO_3 + H_2O \leftrightarrows KHCO_3 + KOH$ | pH > 7<br>basic | $K_h = \dfrac{K_w}{K_{i2\,H_2CO_3}}$ |
| NaCN<br>salt of weak acid | | | |
| $NH_4NO_3$<br>salt of weak base | | | |
| $NH_4CN$<br>salt of weak base<br>and weak acid | | | |

2. Specify the direction of equilibrium shift in the hydrolysis reaction $Zn^{2+} + HOH \leftrightarrows ZnOH+ + H^+$, $\Delta H > 0$. Fill in the table:

| Conditions | Direction of equilibrium shift |
|---|---|
| Adding $ZnCl_2$ | $\leftarrow$ |
| Adding HCl | |
| Adding $H_2O$ | |
| Adding NaOH | |
| Adding $Na_2CO_3$ | |
| Increasing temperature | |

### Test-questions and problems

1. Define the process of hydrolysis of salts. Reaction of the exchange interaction of salt ions with _____

_____

2. What does the degree of hydrolysis (h) show?

h shows _____

_____

3. How the degree of hydrolysis is depended on the concentration of salt? Fill in the table:

| $c$(NaCN) | Calculate the value of degree of hydrolysis (h) | Conclusion |
|---|---|---|
| 0.001 | $h = \sqrt{\dfrac{K_h}{c}} = \sqrt{\dfrac{K_w}{K_i HCN \times c}} = \sqrt{\dfrac{10^{-14}}{8 \times 10^{-10} \times 1 \times 10^{-3}}} = 0.112$ | |
| 0.01 | | |
| 0.1 | | |

4. Write the expression of hydrolysis constants for the three types of salts. Fill in the table:

| Formula of salt | Type of salt | Expression of $K$h |
|---|---|---|
| $NaCH_3COO$ | Salt of weak acid and strong base | |
| $NH_4Cl$ | Salt of weak base and strong acid | |
| $NH_4CH_3COO$ | Salt of weak base and weak acid | |

5. Fill in the table:

| Formula of salt | Ionic and molecular equations of hydrolysis reaction | Types of salts formed due to hydrolysis process |
|---|---|---|
| $FeSO_4$ | | |
| $Na_2CO_3$ | | |
| $NH_4Cl$ | | |

6. Complete the molecular equation for the reaction irreversible hydrolysis of binary covalent compounds:

$CaH_2 + 2H_2O \rightarrow$

$CaC_2 + 2H_2O \rightarrow$

$BCl_3 + 3H_2O \rightarrow$

$PCl_5 + 4H_2O \rightarrow$
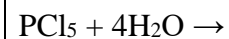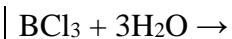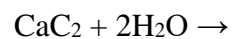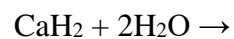
7. Calculate pH of 0.01 M solution of salts. Fill in the table:

| Compounds | Calculation of $K_h$ | c(H$^+$) or c(OH$^-$), mole/L | pH |
|---|---|---|---|
| NaCN | $K_h = \dfrac{1 \times 10^{-14}}{8 \times 10^{-10}} = 1.25 \times 10^{-5}$ | $c(OH^-) = \sqrt{K_h \times c} = \sqrt{1.25 \times 10^{-5} \times 1 \cdot 10^{-2}} = 3.54 \times 10^{-4}$ <br> pOH= –log[OH$^-$], pOH = –log3.54×10$^{-4}$ = 4 – 0.54 = 3.46 | pH = 14 – pOH <br> pH = 14 – 3.46 = 10.54 |
| | NaCN → Na$^+$ + CN$^-$ <br> CN$^-$ + HOH $\leftrightarrows$ HCN + OH$^-$ | | |
| K$_2$CO$_3$ | | | |
| | | | |
| NaHCO$_3$ | | | |
| | | | |
| NH$_4$Cl | | | |
| | | | |

*Laboratory Work*

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 1.** **Salts formed by strong bases and weak acids** a) By means of universal test paper determine pH of 0.1 *N* sodium acetate solution. Write ionic-molecular hydrolysis reaction equations and calculate $K_h$. Draw a conclusion as to the ability of anions of weak acids to hydrolyse. | | | |
| b) Pour 5 or six drops of 0.5 *N* sodium carbonate solution into a test-tube, into another one – the same volume of 0.5 *N* sodium sulphate solution. Add one drop of phenolphthalein to each of them and compare colours of solutions. Write ionic-molecular hydrolysis reaction equations. Calculate the degree and the constant of hydrolysis, hydroxide-ions concentration and pH of salts solutions. Fill in the table with the results obtained. | | | |
| **Experiment 2.** **Salts produced by weak bases and strong acids** By means of universal test paper, determine the medium reaction in 0.1 *N* ammonia chloride solution. Write ionic-molecular hydrolysis reaction equations and calculate $K_h$. | | | |

*The example of control-test*

1. Give examples of salts, which are hydrolyzed by the cation.
2. Among the given compounds, indicate the salts undergoing hydrolysis: $NaNO_3$, $ZnSO_4$, KI. Write ionic-molecular equations for the reactions of hydrolysis.
3. Write the ionic and molecular equation for the hydrolysis of iron (II) sulfate $FeSO_4$ on the first step if basic salt $(FeOH)_2SO_4$ is formed. Specify the reaction medium in a solution of this salt.
4. Calculate the constant of hydrolysis ($K_h$) of sodium sulfite. $K_{a1}$ $H_2SO_3 = 2 \times 10^{-2}$, $K_{a2}$ $H_2SO_3 = 6.3 \times 10^{-8}$.
5. Specify the direction of equilibrium shift in the hydrolysis reaction: $Zn^{2+} + H_2O \leftrightarrows ZnOH^+ + H^+$ if adding acid.

# LESSON № ___

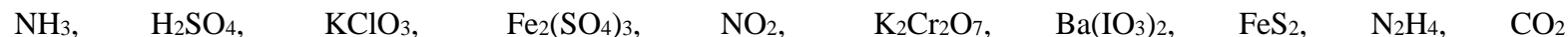## Topic: OXIDATION-REDUCTION REACTIONS

*Theoretical issues*

Key concepts of oxidation-reduction processes: oxidation numbers of elements in compounds, oxidizing agent, reducing agent, processes of oxidation and reduction. Main oxidizing and reducing agents. Shift in oxidation-reduction properties of elements and their compounds in periods and groups of D. I. Mendeleev's periodic table. Determining oxidation-reduction reaction equations: electron balance method, electron-ionic method (half-reactions method). Main types of oxidation-reduction reactions. Conditions of oxidation-reduction reactions. Oxidation-reduction potentials and determination of directions of oxidation-reduction reactions. Equivalents and equivalent masses of substances in oxidation-reduction reactions.

*Basic concepts*

| | |
|---|---|
| **An oxidation-reduction reaction** | is the reaction that results from oxidation and reduction processes occurring simultaneously, resulting in a change in the oxidation state of the elements |
| **Oxidizing agent** | is a substance that accepts electrons. As a result, its oxidation state decreases. |
| **Reducing agent** | is a substance that gives away electrons. As a result, its oxidation state increases. |
| **Intermolecular redox reactions** | redox reactions in which elements that change the oxidation state are part of various molecules |
| **Intramolecular redox reactions** | redox reactions in which elements that change the oxidation state are part of one molecule |
| **Disproportionation Reactions** | The same substance is both oxidized and reduced |
| **Oxidation state** | is the charge of an atom if all bonds it formed were ionic bonds |
| **An electrochemical cell** ($E°_{cell}$) | is a device in which an oxidation-reduction reaction is carried out in the form of separate half-reactions for oxidation and reduction. $E°_{cell} = E°_{red} - E°_{ox}$ |

*Home task*

1. Determine the oxidation state of elements in compounds:

$NH_3$,     $H_2SO_4$,     $KClO_3$,     $Fe_2(SO_4)_3$,     $NO_2$,     $K_2Cr_2O_7$,     $Ba(IO_3)_2$,     $FeS_2$,     $N_2H_4$,     $CO_2$

2. Among the given compounds $H_2S$, $Na_2SO_3$, $H_2O_2$, $K_2Cr_2O_7$, $KMnO_4$, $PbO_2$, $KI$, $NH_3$, $NaNO_2$, $HNO_3$, $H_2SO_4$, $P$, $H_2SO_3$, $HCl$ – indicate those displaying only oxidation or only reduction properties, and the ones possessing oxidation-reduction duality. Fill in the table with the formula of compounds with are using table 9:

| Oxidation properties | Reduction properties | Oxidation-reduction duality |
|---|---|---|
| | | |

3. Indicate the type of oxidation-reduction reactions. Fill in the table:

| Reaction | Type of oxidation-reduction reaction |
|---|---|
| $2NO_2 + H_2O = HNO_2 + HNO_3$ | |
| $Cl_2 + 2KBr = Br_2 + 2KCl$ | |
| $2KClO_3 \rightarrow 2KCl + 3O_2$ | |

4. Select the coefficients by electron-ionic method:

a) $FeSO_4 + KMnO_4 + H_2SO_4 = Fe_2(SO_4)_3 + MnSO_4 + K_2SO_4 + H_2O$

$2Fe^{2+} \qquad \leftrightarrows 2Fe^{3+}$

$MnO_4^- \qquad \leftrightarrows Mn^{2+}$

_____

b) $MnO_2 + KClO_3 + NaOH = Na_2MnO_4 + KCl + H_2O$

$MnO_2 \qquad \leftrightarrows MnO_4^{2-}$

$ClO_3^- \qquad \leftrightarrows Cl^-$

_____

## *Test-questions and problems*

5. Determine the oxidation state of nitrogen in compounds: $NH_3$, $N_2O$, $NO_2$, $N_2O_5$, $NO$, $N_2O_3$.

6. Determine the oxidation state of chromium in compounds: $K_2CrO_4$, $Cr_2O_3$, $K_2Cr_2O_7$, $Cr_2(SO_4)_3$, $Na_3[Cr(OH)_6]$.

7. Specify oxidation-reduction reactions:

☐ $H_2 + Br_2 = 2HBr$　　　☐ $NH_4Cl = NH_3 + HCl$　　　☐ $NH_4NO_2 = N_2 + 2H_2O$

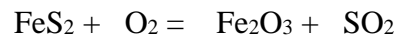☐ $2K_2CrO_4 + H_2SO_4 = K_2Cr_2O_7 + K_2SO_4 + H_2O$　　　☐ $SO_2 + Br_2 + 2H_2O = 2HBr + H_2SO_4$
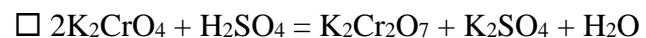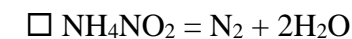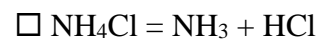
8. Specify oxidizing and reducing agent:

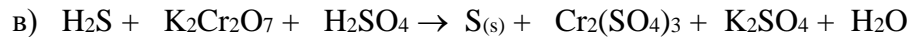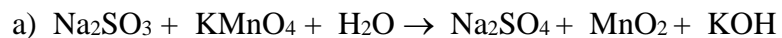$Zn + H_2SO_4 = ZnSO_4 + H_2$        $H_2S + Cl_2 = S + 2HCl$        $2KClO_3 = 2KCl + 3O_2$
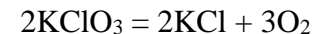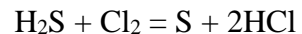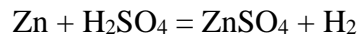
9. Specify if the process is oxidation or reduction:

| $S \rightarrow SO_4^{2-}$ | oxidation | $Cl^- \rightarrow ClO_3^-$ | | $2IO_3^- \rightarrow I_2$ | |
|---|---|---|---|---|---|
| $S \rightarrow S^{2-}$ | | $Br_2 \rightarrow 2Br^-$ | | $MnO_4^- \rightarrow MnO_4^{2-}$ | |

10. Select the coefficients by electronic method. Indicate type of oxidation-reduction reactions:
$$FeS_2 + O_2 = Fe_2O_3 + SO_2$$

11. Select the coefficients by electron-ionic method:

a) $Na_2SO_3 + KMnO_4 + H_2O \rightarrow Na_2SO_4 + MnO_2 + KOH$

   $SO_3^{2-}$        $\leftrightarrows SO_4^{2-}$

   $MnO_4^-$        $\leftrightarrows MnO_2$

b) $NaNO_2 + KMnO_4 + H_2SO_4 \rightarrow NaNO_3 + MnSO_4 + K_2SO_4 + H_2O$

   $NO_2^-$        $\leftrightarrows NO_3^-$

   $MnO_4^-$        $\leftrightarrows Mn^{2+}$

в) $H_2S + K_2Cr_2O_7 + H_2SO_4 \rightarrow S_{(s)} + Cr_2(SO_4)_3 + K_2SO_4 + H_2O$

   $H_2S$        $\leftrightarrows S\downarrow$

   $Cr_2O_7^{2-}$        $\leftrightarrows 2Cr^{3+}$

г) $NaBr + NaBrO_3 + H_2SO_4 \rightarrow Br_2 + Na_2SO_4 + H_2O$

   $2Br^-$        $\leftrightarrows Br_2$

   $2BrO_3^-$        $\leftrightarrows Br_2$
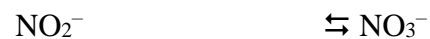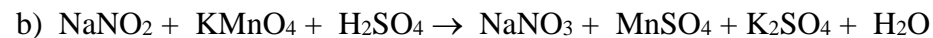
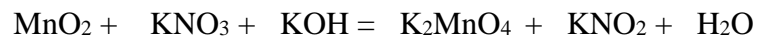# LESSON № ___

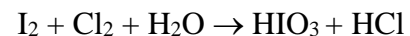## Topic: OXIDATION-REDUCTION REACTIONS

### *Test-questions and problems*

1. Balance the following equations by using the ″half-reaction″ method. Determine the equivalent mass ($E_m$) of oxidizing and reducing agent. Indicate the type of oxidation-reduction reactions:

$MnO_2 + \ KNO_3 + \ KOH = \ K_2MnO_4 + \ KNO_2 + \ H_2O$

$MnO_2 \qquad\qquad \leftrightarrows MnO_4^{2-}$

$NO_3^- \qquad\qquad \leftrightarrows NO_2^-$

_____

$E_m$ (ox. agent) = \qquad $E_m$ (red. agent) =

Type of reaction:

$I_2 + Cl_2 + H_2O \rightarrow HIO_3 + HCl$

$I_2 \qquad\qquad \leftrightarrows 2IO_3^-$

$Cl_2 \qquad\qquad \leftrightarrows 2Cl^-$

_____

$E_m$ (ox. agent) = \qquad $E_m$ (red. agent) =

Type of reaction:

$MnSO_4 + PbO_2 + HNO_3 \rightarrow HMnO_4 + PbSO_4 + Pb(NO_3)_2 + H_2O$

$Mn^{2+} \qquad\qquad \leftrightarrows MnO_4^-$

$PbO_2 \qquad\qquad \leftrightarrows Pb^{2+}$

_____

$E_m$ (ox. agent) = \qquad $E_m$ (red. agent) =

Type of reaction:

$K_3[Cr(OH)_6] + H_2O_2 \rightarrow K_2CrO_4 + KOH + H_2O$

$[Cr(OH)_6]^{3-} \qquad\qquad \leftrightarrows CrO_4^{2-}$

$H_2O_2 \qquad\qquad \leftrightarrows 2OH^-$

_____

$E_m$ (ox. agent) = \qquad $E_m$ (red. agent) =

Type of reaction:

$$Cl_2 + \ KOH \ \xrightarrow{t°} \ KCl + \ KClO_3 + \ H_2O$$

$$Cl_2 \qquad\qquad\qquad \leftrightarrows 2Cl^-$$

$$Cl_2 \qquad\qquad\qquad \leftrightarrows 2ClO_3^-$$

_____
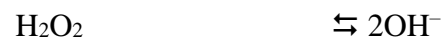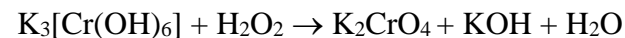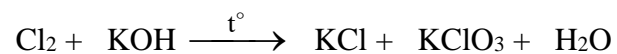
$E_m$ (ox. agent) = $\qquad\qquad$ $E_m$ (red. agent) =
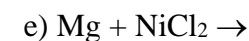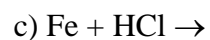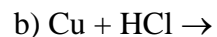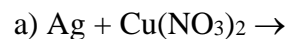
$\qquad\qquad$ Type of reaction:

2. Use standards electrode potentials (*Table 10*) to determine the standard cell potential (E°cell) following reaction:

| Reaction | $E°_{cell}$ | Conclusion |
|---|---|---|
| $2KCl + I_2 = Cl_2 + 2KI$ | $E°_{cell} = E^0{}_{I_2/2I^-} - E^0{}_{Cl_2/2Cl^-} = 0{,}536 - 1{,}359 = -0{,}823$ (V) | Reaction impossible |
| $6FeSO_4 + K_2Cr_2O_7 + 7H_2SO_4 = 3Fe_2(SO_4)_3 + Cr_2(SO_4)_3 + K_2SO_4 + 7H_2O$ | | |
| $16HCl + 2KMnO_4 = 5Cl_2 + 2MnCl_2 + 2KCl + 8H_2O$ | | |
| $2KI + SnCl_4 = I_2 + SnCl_2 + 2KCl$ | | |

3. Determine which ions can be oxidized using bromine water ($Br_2 + 2\bar{e} \leftrightarrows 2Br^-$; $E^0 = 1{,}07$ V):

| Reaction | $E°_{cell}$ | Conclusion |
|---|---|---|
| $Fe^{2+} \rightarrow Fe^{3+}$; $E^0 = 0.77$ V | | |
| $Mn^{2+} \rightarrow MnO_4^-$; $E^0 = 1.51$ V | | |
| $Sn^{2+} \rightarrow Sn^{4+}$; $E^0 = 0.157$ V | | |

4. By means of numerical values of The Activity Series of Metals from Table 8 to predict, a spontaneous reaction will occur in the forward direction in each case.

a) $Ag + Cu(NO_3)_2 \rightarrow$ $\qquad\qquad\qquad$ b) $Cu + HCl \rightarrow$

c) $Fe + HCl \rightarrow$ $\qquad\qquad\qquad$ d) $Zn + MgSO_4 \rightarrow$ $\qquad\qquad\qquad$ e) $Mg + NiCl_2 \rightarrow$

*Laboratory Work*

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 1.**<br>**Reduction properties of metals**<br>    To each of two test tubes add ten-twelve drops: to test-tube 1 – 0.2 $N$ copper (II) sulphate solution, to test-tube 2 – 0.2 $N$ zinc sulphate solution. Sink a piece of iron wire into each one. Explain the formation of red bloom on the iron surface in copper sulphate solution two-three minutes later. Explain the lack of blue coloration in test-tube 2.<br>    Calculate $E°_{cell}$ of this reaction. | | | |
| **Experiment 2.**<br>**Oxidation properties of potassium permanganate depending on the medium reaction**<br>    Introduce two-three drops of 0.1 $N$ potassium permanganate solution to each of three test tubes. To test-tube 1, add two drops of 2 $N$ sulphuric acid solution, to test-tube 2 – two drops of distilled water, to test-tube 3 – two drops of 10% sodium hydroxide solution, by mass. After that add, in drops, 0.1 $N$ sodium sulphite solution to each of the test tubes until the change of solution colour is observed. Write the reaction equations and select the coefficients using half-reactions method. Explain the difference in oxidation activity of potassium permanganate depending on the medium reaction. Calculate $E°_{cell}$ of this reaction. | | | |

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| *Experiment 3.* <br> **Disproportionation of iodine in alkaline medium** <br> Place one-two iodine crystals into a test-tube, add three-five drops of 10% sodium hydroxide solution, by mass, and heat it. Notice the shift of solution colour and dissolving of the precipitate. To the cooled solution add diluted sulphuric acid solution, in drops, untill the reaction of the medium becomes weak-acid. What is happening? Write the reaction equation and select the coefficients by half-reactions method. Calculate $E°_{cell}$ of this reaction. | | | |

### *The example of control-test*

1. Give a definition of "Red-Ox reactions".
2. Indicate type of oxidation-reduction reactions: $3N_2H_4 = N_2 + 4NH_3$

3. Select the stoichiometric coefficients by electronic method: $AgNO_3 \xrightarrow{t°} Ag^0 + NO_{2(g)} + O_2$
4. Select the coefficients by electron-ionic method: $FeSO_4 + Br_2 + H_2SO_4 \rightarrow Fe_2(SO_4)_3 + HBr + H_2O$
5. Comparing the standard electrode potentials of the separate attended pair, specify in what solution (acidic or alkaline) an aluminium shows more strong reduction properties:

$$Al^{3+} + 3\bar{e} \leftrightarrows Al^0 \qquad\qquad E^0 = -1,66 \text{ V}$$
$$[Al(OH)_6]^{3-} + 3\bar{e} \leftrightarrows Al^0 + 6OH^- \qquad E^0 = -2,35 \text{ V}$$

# LESSON № ___

## Topic: COORDINATION COMPOUNDS

*Theoretical issues*

Determining classes of coordination compounds and key concepts: central atom, ligand, coordination number, coordination ion. Classification and nomenclature of coordination compounds. Equilibrium in the coordination compounds solutions. General and step instability constants of coordination ion. Isomerism of coordination compounds. Theory of chemical bonds in coordination compounds (Valence Bonds Method). Application of coordination compounds in pharmacy and medicine.

*Basic concepts*

| | |
|---|---|
| **Coordination Compounds** | is a substance containing complex ions |
| **A complex ion** | is a combination of a central metal ion and ligands coordinated around it |
| **Central atom** | is an atom in a complex ion having free atomic orbitals and acting as an acceptor for the formation of a chemical bond with ligands |
| **Ligands** | ions or molecules having one or more electron pairs that are capable of forming a bond by a donor-acceptor mechanism with a central atom |
| **Coordination number** | is the number of ions and atoms around a central atom |
| **Monodentate ligand** | is a ligand that has only one atom that coordinates directly to the central atom in a complex. For example, ammonia and chloride ion are monodentate ligands of copper in the complexes $[Cu(NH_3)_4]^{2+}$ and $[CuCl_4]^{2-}$ |
| **Isomerism** | is the phenomenon in which more than one compounds have the same chemical formula but different chemical structures. Chemical compounds that have identical chemical formulae but differ in properties and the arrangement of atoms in the molecule are called isomers. The word "isomer" is derived from the Greek words "isos" and "meros", which mean "equal parts". This term was coined by the Swedish chemist Jacob Berzelius in the year 1830 |
| **Geometric isomerism** | is refers to the formation of nonequivalent structures based on the positions at which ligands are attached to a central metal ion in a complex ion |
| **Ionization isomerism** | Arises when a ligand from the coordination sphere of metal ion is exchanged for an ion outside the coordination sphere |
| **Hydrated isomerism** | Isomers of crystalline complexes that differ in whether water is present inside or outside the coordination sphere |
| **Coordination isomerism** | Arises in certain coordination compounds having both a complex cation and complex anion. An interchange of ligands between the two complex ions leaves the composition of the compound unchanged |

*Home task*

1. Specify component parts of coordination compounds. Fill in the table:

| Coordination compounds | Ions of external sphere | Coordination ion, charge | Central ion and its oxidation number | Ligands | Coordination number | Name |
|---|---|---|---|---|---|---|
| $[Ag(NH_3)_2]Cl$ | $Cl^-$ | $[Ag(NH_3)_2]^+$ | $Ag^{+1}$ | $NH_3$ | 2 | diamineargentum (I) chloride |
| $[Cr(H_2O)_5Cl]Cl_2$ | | | | | | |
| $H_2[SiF_6]$ | | | | | | |
| $Na_3[Al(OH)_6]$ | | | | | | |
| $K_3[Fe(CN)_6]$ | | | | | | |
| $H[AuCl_4]$ | | | | | | |
| $[Pt(NH_3)_2Cl_2]$ | | | | | | |

2. Classification of coordination compounds:

| Formula of coordination compounds | Classification | | |
|---|---|---|---|
| | on the charge of complex ion (cation, anion, neutral) | on the acidity of solution (acids, bases, salts) | by the nature of ligands (aquacomplexes, aminocomplexes, acidocomplexes, hydroxocomplexes, carbonyliccomplexes) |
| $[Cu(NH_3)_4]SO_4$ | cation | coordination salt | aminocomplex |
| $H[AuCl_4]$ | | | |
| $[Cr(H_2O)_6]Cl_3$ | | | |
| $K_3[Fe(CN)_6]$ | | | |
| $[Ag(NH_3)_2]OH$ | | | |
| $[Ni(CO)_4]$ | | | |
| $[Pt(NH_3)_2Cl_2]$ | | | |
| $Na_2[Zn(OH)_4]$ | | | |

*Test-questions and problems*

1. Give determination of coordination compounds and make examples. What are the components of the coordination compounds?

$$K_3[Fe(CN)_6]$$
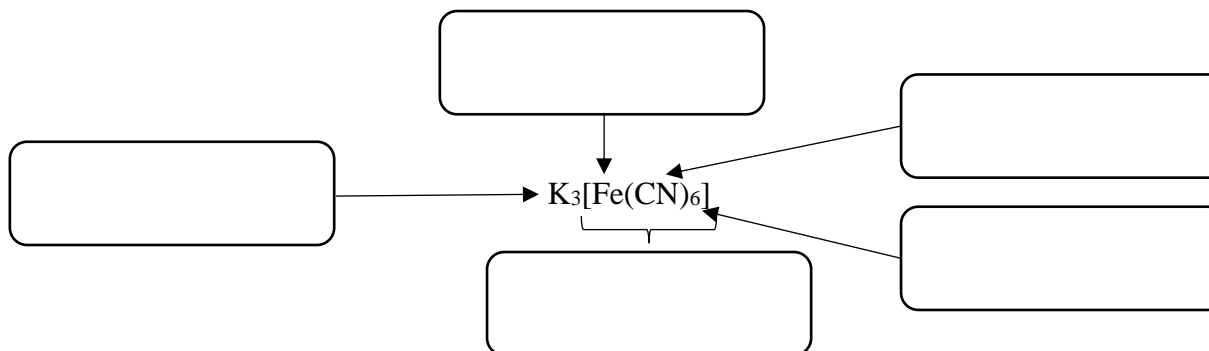
2. Classificate the coordination compounds:

| on the charge of complex ion | on the acidity of solution | by the nature of ligands |
|---|---|---|
|  |  |  |

3. Name the coordination compounds:

| | |
|---|---|
| $[Cu(NH_3)_4](OH)_2$ | |
| $[Cr(H_2O)_4Cl_2]Cl$ | |
| $K_4[Fe(CN)_6]$ | |
| $Na_2[Sn(OH)_6]$ | |
| $[Mn_2(CO)_{10}]$ | |

54

4. Name types of isomerism (geometric, hydrated, ionization, coordinating) of complex compounds:

| | |
|---|---|
| $[Co(NH_3)_5Br]SO_4$, $[Co(NH_3)_5SO_4]Br$ | |
| $[Cr(OH_2)_6]Cl_3$, $[Cr(OH_2)_5Cl]Cl_2 \cdot H_2O$, $[Cr(OH_2)_4Cl_2]Cl \cdot 2H_2O$ | |
| $[Pt(NH_3)_2Cl_2]$ | |
| $[Co(NH_3)_6] \cdot [Cr(CN)_6]$, $[Cr(NH_3)_6] \cdot [Co(CN)_6]$ | |

5. Dissociation of coordination compounds. Fill in the table:

| Coordination compound | Equation of dissociation of coordination compounds | | Expression of instability constants |
|---|---|---|---|
| K[Ag(CN)₂] | Primary dissociation | $K[Ag(CN)_2] \rightarrow K^+ + [Ag(CN)_2]^-$ | – |
| | Secondary general dissociation | $[Ag(CN)_2]^- \leftrightarrows Ag^+ + 2CN^-$ | $K_{in\ gen.} = \dfrac{[Ag^+][CN^-]^2}{[[Ag(CN)_2]^-]}$ |
| [Cu(NH₃)₄]SO₄ | Primary dissociation | | – |
| | Secondary general dissociation | | $K_{in\ gen.} =$ |
| [Pt(NH₃)₂Cl₂] | Primary dissociation | | – |
| | Secondary general dissociation | | $K_{in\ gen.} =$ |

6. Use the valence bond method and spectrochemical series of ligands, explain the mechanism of formation of complex ion. Do the conclusions about coordination number, hybridization of central atom AO, magnetic properties of complex ion and its structure.  Fill in a table:

| $CN^- > CO > NO_2^- >$ | $En > NH_3 > SCN^- >$ | $H_2O >$ | $OH^- > F^- > Cl^- > Br^- > I^-$ |
|:---:|:---:|:---:|:---:|
| Strong field | Ligands of average force | | Weak field |
| Couple electrons of central metal | | | Do not couple electrons of central metal |

| Formula of complex ion | Valence electronic formula of central ion | Nature of ligand | Electronic-graphic formula of central atom and complex ion | Conclusion |
|---|---|---|---|---|
| $[CoF_6]^{3-}$ | $Co^{3+}\ 3d^6 4s^0$ | weak field, does not couple electrons |  | c.n. = 6, $sp^3d^2$-hybridization, paramagnetic, octahedron structure |
| $[Fe(CN)_6]^{3-}$ | | | | |
| $[Cu(NH_3)_4]^{2+}$ | | | | |

## *The example of control-test*

1. Determine charge of complex ion, oxidation degree and coordination number of central atom $[Cu(NH_3)_4](OH)_2$. Name the coordination compound.
2. Name types of isomerism in complex compounds: $[Co(NH_3)_5Br]SO_4$, $[Co(NH_3)_5SO_4]Br$.
3. Use the valence bond method, explain the mechanism of formation of complex ion $[Fe(CN)_6]^{3-}$. Specify the type of hybridization of atomic orbitals of complex ion, magnetic properties and geometrical form of complex ion.
4. Write equations for primary and secondary step dissociation of complex compounds: $[Ag(NH_3)_2]Cl$ and the expressions for general instability constants.
5. Calculate molar concentration of hydroxide ions of 0.01 $M$ solution $[Cu(NH_3)_4](OH)_2$.

# LESSON № ___

## Topic: *p*-ELEMENTS OF IIIA – VA GROUPS

*Theoretical issues*

General characteristics of IIIA group elements. Physical and chemical properties of Boron, Aluminium and their compounds.

General characteristics of p-elements of IV group. Physical and chemical properties of Carbon, Silicon, Tin, Lead and their compounds. Allotropy of the Carbon. Activated charcoal. Carbon (IV) oxide. Equilibrium in $CO_2$ water solution. Carbonates and hydrogencarbonates. Nature of a bond of carbon (II) oxide. Reduction properties of tin (II) chloride and oxidation properties of lead (IV) oxide.

General characteristics of *p*-elements of V group. Physical and chemical properties of Nitrogen, Phosphorus, Antimony, Bismuth, Arsenic and their compounds. Possible oxidation numbers of Nitrogen in compounds. Physical and chemical properties of ammonia. Ammonium salts. Solubility in water and hydrolysis. Decomposition of ammonium salts on heating. Oxides of Nitrogen. Nitrous acid, nitrites, oxidation-reduction duality. Nitric acid. Oxidizing properties. Phosphorus. Allotropy of the Phosphorus. Phosphorus oxides. Orthophosphoric acid. Elements of Arsenic subgroup. General characteristics. Characteristic oxidation states in compounds.

Reactions of qualitative identification of borate, carbonate, silicate, tin (II) and lead (II) cations, ammonium cation, phosphate and arsenic compounds, bismuth (III) cation.

Biological role of *p*-elements of III–V groups. Application of their compounds in medicine and pharmaceutical analysis.

*Home task*

1. Fill in the table: write the electron configuration for the elements, the possible oxidation states and examples of compounds with the indicated oxidation states.

| Elements | Electron configuration | | Examples of compounds |
|----------|------------------------|--------------|-----------------------|
|          | basic state            | excited state |                       |
| B        |                        |              |                       |
| Al       |                        |              |                       |

2. Write the formula of oxides and hydroxides of elements of the IV A group, list their properties (basic, amphoteric, acidic):
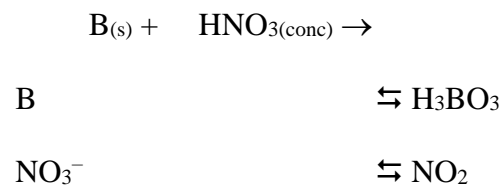
| Elements | Formula of oxide, its properties and name | Formula hydroxide, its properties and name |
|----------|-------------------------------------------|--------------------------------------------|
| C        |                                           |                                            |
| Si       |                                           |                                            |
| Sn       |                                           |                                            |
| Pb       |                                           |                                            |

3. Calculate $[H^+]$ and pH of the 0.1 $M$ solution of hydrocyanic acid ($K_a$ HCN $= 8\times10^{-10}$).

4. Explain the mechanism of formation of chemical bonds in a molecule of nitrogen.

5. Calculate the degree of dissociation and concentration of hydroxide ions in 0.1 $M$ solution of ammonia ($NH_3 \cdot H_2O$), $K_b = 1.8\times10^{-5}$:

6. Write equation of the reactions phosphorus with excess and lack of oxygen:

$P + O_2$ (lack) $=$                    $P + O_2$ (excess) $=$

7. Complete the reaction equation:

$P_2O_5 + H_2O =$            $P_2O_5 + 2H_2O =$            $P_2O_5 + 3H_2O =$

8. Write the equations of step and total dissociation of phosphoric acid, expression of the general dissociation constant:

### Test-questions and problems

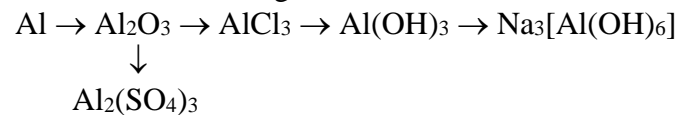1. Write the equation of reaction of boron with nitric acid. Select the coefficients by electron-ionic method.

$B_{(s)} + \quad HNO_{3(conc)} \rightarrow$

B                                    $\leftrightarrows H_3BO_3$

$NO_3^-$                                $\leftrightarrows NO_2$

2. Write the equation of reactions demonstration the following transformations:

$$B \rightarrow B_2O_3 \rightarrow H_3BO_3 \rightarrow Na_2B_4O_7 \rightarrow H_3BO_3 \rightarrow B_2O_3$$
$$\downarrow$$
$$B(OC_2H_5)_3$$
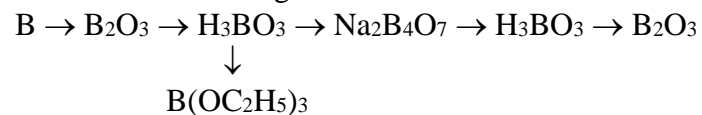
3. Write the reactions that characterize the reduction properties of Al and select the coefficients by electron-ionic method.

$$Al + NaOH + H_2O \rightarrow \qquad\qquad\qquad\qquad Al + H_2SO_{4((dilute)} \rightarrow$$

Al $\qquad\qquad \leftrightarrows [Al(OH)_6]^{3-}$ $\qquad\qquad\qquad\qquad$ Al $\qquad\qquad \leftrightarrows Al^{3+}$

$H_2O \qquad\qquad \leftrightarrows H_2$ $\qquad\qquad\qquad\qquad\qquad$ $2H^+ \qquad\qquad \leftrightarrows H_2$

4. Write the equation of reactions demonstration the following transformations:

$$Al \rightarrow Al_2O_3 \rightarrow AlCl_3 \rightarrow Al(OH)_3 \rightarrow Na_3[Al(OH)_6]$$
$$\downarrow$$
$$Al_2(SO_4)_3$$

5. Write the equation of reactions demonstration the following transformations:

$$C \rightarrow CO_2 \rightarrow NaHCO_3 \rightarrow Na_2CO_3 \rightarrow CO_2 \rightarrow H_2CO_3$$
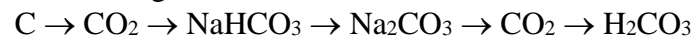
6. Write the equation of reactions demonstration the following transformations and name the compounds:

$$Sn \rightarrow SnCl_2 \leftrightarrows Sn(OH)_2 \rightarrow Na_2[Sn(OH)_4]$$

7. Write electron configuration of the Nitrogen atom: _____

Fill in the table:

| Oxidation states | –3 | –2 | –1 | 0 | +1 | +2 | +3 | +4 | +5 |
|---|---|---|---|---|---|---|---|---|---|
| Compounds | | | | | | | | | |
| Red-Ox properties | | | | | | | | | |

8. Explain the mechanism of formation of chemical bonds in a molecule of ammonia ($NH_3$) and ammonium cation ($NH_4^+$) from a position of valence bond method (*VB*).

9. Define valence and oxidation state of Nitrogen atom in a molecule of nitric acid, $HNO_3$. Draw its graphic formula:
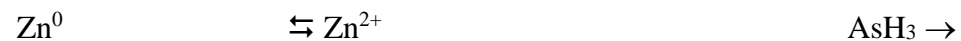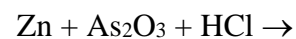
10. Write the disproportionation reaction of phosphorus in alkaline medium and its oxidation with nitric acid. Select the coefficients by electron-ionic method:
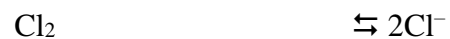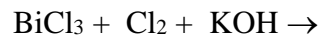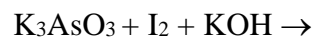
$$P + \ NaOH + \ H_2O \rightarrow$$

P $\leftrightarrows [PO_2H_2]^-$

P $\leftrightarrows PH_3$

$$P + \ HNO_{3(conc)} + \ H_2O \rightarrow$$

P $\leftrightarrows H_3PO_4$

$NO_3^-$ $\leftrightarrows NO_2$
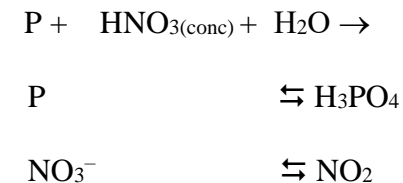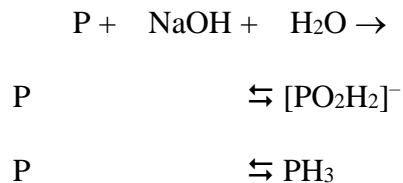
11. Write the names and graphic formulas of acids, indicate their basicity:

| $H[PO_2H_2]$ | $H_2[PO_3H]$ | $H_3PO_4$ |
|---|---|---|
| | | |

12. Write the reaction of the qualitative identification of arsenic by March method, if the sample for analysis contains arsenic (III) oxide. Select the coefficients by electron-ionic method:

$Zn + As_2O_3 + HCl \rightarrow$

$Zn^0 \qquad \leftrightarrows Zn^{2+}$ $\qquad\qquad\qquad\qquad AsH_3 \rightarrow$

$As_2O_3 \qquad \leftrightarrows AsH_3$

13. Complete the reaction equation; select the coefficients by electron-ionic method:

$K_3AsO_3 + I_2 + KOH \rightarrow$ $\qquad\qquad\qquad\qquad KI + K_3AsO_4 + H_2SO_4 \rightarrow$

$AsO_3^{3-} \qquad \leftrightarrows AsO_4^{3-}$ $\qquad\qquad\qquad 2I^- \qquad \leftrightarrows I_2^0$

$I_2^0 \qquad \leftrightarrows 2I^-$ $\qquad\qquad\qquad\qquad AsO_4^{3-} \qquad \leftrightarrows AsO_3^{3-}$

$BiCl_3 + Cl_2 + KOH \rightarrow$ $\qquad\qquad\qquad\qquad MnSO_4 + NaBiO_3 + HNO_3 \rightarrow$

$Bi^{3+} \qquad \leftrightarrows BiO_3^-$ $\qquad\qquad\qquad Mn^{2+} \qquad \leftrightarrows MnO_4^-$

$Cl_2 \qquad \leftrightarrows 2Cl^-$ $\qquad\qquad\qquad\qquad BiO_3^- \qquad \leftrightarrows Bi^{3+}$

*Laboratory Work*

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 1.**<br>**Reaction of qualitative identification of orthoboric acid**<br>Into a porcelain crucible place several crystals of orthoboric acid, one-two drops of concentrated sulphuric acid, and five-six drops of ethanol. Stir the mixture with a glass stick and ignite the formed ethyl ester of boric acid. Observe the coloration of the flame. Write the equation for obtaining ethyl ester of boric acid. Indicate the role of sulphuric acid. | | | |
| **Experiment 2.**<br>**Obtaining silicic acid**<br>Place four-five drops of saturated sodium silicate solution into a test-tube and add four-five drops of 2 *N* hydrochloric acid solution. Stir the contents of the test-tube with a glass stick. Note the formation of gelatinous precipitate (gel) of silicic acid. Write the reaction equation. | | | |
| **Experiment 3.**<br>**Sodium silicate hydrolysis**<br>Add one-two drops of phenolphthalein to a test-tube with three-four drops of saturated sodium silicate solution. Record the observations. Write ionic and molecular reaction equation. | | | |

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 4.**<br>**Obtaining ammonia**<br>    Place 1 microspatula of ammonium chloride and 1 microspatula of calcium hydroxide into a dry test-tube. Stir the contents of the test-tube with a glass stick and heat carefully. Bring close to the orifice of the test-tube, first – a wet strip of red litmus paper, then – a glass stick wetted with concentrated hydrochloric acid. Write the reactions equations for obtaining ammonia and for the interaction of the latter with a hydrochloric acid.<br>    This is the reaction of qualitative identification of ammonium cation. | | | |
| **Experiment 5.**<br>**Obtaining magnesium-ammonium phosphate**<br>    Place three-four drops of 0.1 $M$ sodium hydrogenphosphate solution into a test-tube and add several drops of magnesium chloride mixture ($MgCl_2$ + $NH_3 \cdot H_2O$ + $NH_4Cl$). Note the colour and the crystalline structure of the precipitate. Write ionic and molecular reaction equations. Explain the necessity of using the excess of ammonium chloride.<br>    This is the reaction of qualitative identification of phosphate-ion. | | | |

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 6.**<br>**Antimony (III) and bismuth (III) salts hydrolysis**<br>    Place three-four drops of saturated antimony (III) or bismuth (III) salt solution into a test-tube; add, in drops, distilled water until the formation of white precipitate. Write ionic and molecular reaction equations for salt hydrolysis of the 1st and 2nd steps with oxosalt formation. To the precipitate of oxosalt add, in drops, concentrated hydrochloric acid till its complete dissolving. Write the reaction equation. Indicate the direction of shifting of chemical equilibrium of the salt hydrolysis reaction when the solution is acidified and diluted. | | | |
| **Experiment 7.**<br>**Oxidation properties of bismuth (III) compounds**<br>    Place one-two drops of 0.5 $M$ tin (II) chloride solution into a test-tube and, in drops, add 2 $N$ sodium hydroxide solution till the precipitate of Sn(OH)$_2$ is produced and later on dissolved. To the solution obtained add one drop of 0.5 $M$ bismuth (III) salt solution. Notice the precipitate of metallic bismuth. Write the equations for corresponding reactions.<br>    This is the reaction of qualitative identification of bismuth (III) cation. | | | |

### *The example of control-test*

1. Among the following compounds indicate substances that have only reducing properties: $NH_2OH$, $NH_4Cl$, $N_2H_4$, $NaNO_3$, $NH_3$, $N_2$.
2. Complete the reaction equations and select the coefficients by electron-ionic method: $BiCl_3 + Cl_2 + KOH \rightarrow KBiO_3 + \ldots$
3. Using Marsh method, write the equation for the reaction of qualitative identification of arsenic in a sample containing arsenic (III) oxide. Select the coefficients by electron-ionic method.
4. Write the equation of reactions demonstration the following transformations: $SiO_2 \rightarrow Na_2SiO_3 \rightarrow H_2SiO_3$.
5. Calculate the mass of nitric acid in 100 mL of 0.1 $M$ solution. ($M_{HNO_3} = 63$ g/mol).

# LESSON № ___

## Topic: *p*-ELEMENTS OF VIA GROUP

### *Theoretical issues*

General characteristics of VIA group elements. Physical and chemical properties of Oxygen, Sulphur, Selenium and their compounds. Oxygen. Oxidation activity of molecular oxygen. Ozone. Classification of binary oxygen-containing compounds: oxides, peroxides, hyper-peroxides. Hydrogen peroxide: obtaining, oxidation-reduction duality.
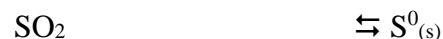
Sulphur. Chemical properties. Sulphur compounds with metals and hydrogen. Hydrogen sulphide. Equilibrium in water solutions. Sulphides and hydrogensulphides. Solubility in water, hydrolysis. Reduction properties. Sulphur (IV) oxide. Equilibrium in water solutions. Sulphites, oxidation-reduction properties of Sulphur (IV) compounds. Sulphur (VI) oxide. Sulphuric acid. Sulphates, solubility in water. Thiosulphates.

Reaction of qualitative identification of hydrogen peroxide, sulphide, sulphite, sulphate, thiosulphate ions.

Biological role of *p*-elements of VI group. Application of their compounds in medicine and pharmaceutical analysis.

### *Home task*

1. Write the reactions of laboratory preparation of oxygen by thermic decomposition of compounds containing large amounts of oxygen.

2. Complete the reaction equation; select the coefficients by electron-ionic method:

$H_2S + SO_2 \rightarrow$

| | |
|---|---|
| $H_2S$ | $\leftrightarrows S^0_{(s)}$ |
| $SO_2$ | $\leftrightarrows S^0_{(s)}$ |

$S + H_2SO_{4(conc)} \rightarrow$

| | |
|---|---|
| $S^0$ | $\leftrightarrows SO_2$ |
| $SO_4^{2-}$ | $\leftrightarrows SO_2$ |

$H_2O_2 + K_2Cr_2O_7 + H_2SO_4 \rightarrow$

| | |
|---|---|
| $H_2O_2$ | $\leftrightarrows O_2$ |
| $Cr_2O_7^{2-}$ | $\leftrightarrows 2Cr^{3+}$ |

$K_2SO_3 + KMnO_4 + H_2SO_4 \rightarrow$

| | |
|---|---|
| $SO_3^{2-}$ | $\leftrightarrows SO_4^{2-}$ |
| $MnO_4^-$ | $\leftrightarrows Mn^{2+}$ |

3. According to the Sulphur oxidation states indicate compounds that can only be a reducing or oxidizing agent or to have redox duality.

$Na_2SO_3$        $H_2S$        $SO_2$        $Na_2S$        $H_2SO_4$

4. Write down the reaction equations, which are characterized by obtaining and properties of sodium thiosulphate: $Na_2SO_3 \rightarrow Na_2SO_3S \rightarrow SO_2$
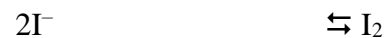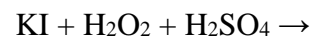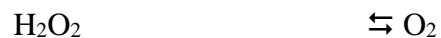
## *Test-questions and problems*

1. Fill in the table: write the electron configuration of the valence electrons for the atoms of Oxygen and Sulphur, the possible oxidation states and examples of compounds with the indicated oxidation states.

| Elements | Valence electrons | Possible oxidation states | Examples of compounds with the indicated oxidation states |
|---|---|---|---|
| O | | | |
| S | | | |

2. Complete the equation for the reaction of ozone ($O_3$) with potassium iodide, which is a qualitative identification of ozone:

$$KI + O_3 \rightarrow$$

3. Complete the reaction equation, confirming the red-ox properties of hydrogen peroxide. Select the coefficients by electron-ionic method:

$H_2O_2 + KMnO_4 + H_2SO_4 \rightarrow$ $\qquad$ $KI + H_2O_2 + H_2SO_4 \rightarrow$

$H_2O_2$ $\leftrightarrows O_2$ $\qquad$ $2I^- \leftrightarrows I_2$

$MnO_4^- \leftrightarrows Mn^{2+}$ $\qquad$ $H_2O_2 \leftrightarrows H_2O$

4. Write the reaction the qualitative identification of hydrogen peroxide.

5. Write the reactions that characterize the reducing properties of $H_2S$:

$H_2S + KMnO_4 + H_2SO_4 \rightarrow$ $\qquad$ $H_2S + HNO_{3(fuming)} \rightarrow$

$H_2S$ $\leftrightarrows S$ $\qquad$ $H_2S \leftrightarrows SO_4^{2-}$

$MnO_4^- \leftrightarrows Mn^{2+}$ $\qquad$ $NO_3^- \leftrightarrows NO_2$

6. Complete the reaction equations, select the coefficients by electron-ionic method:

$S + NaOH \xrightarrow{t^{\circ}}$

| S | $\leftrightarrows S^{2-}$ |
| S | $\leftrightarrows SO_3^{2-}$ |

$Mg + H_2SO_{4(dilut.)} \rightarrow$

| $Mg^0$ | $\leftrightarrows Mg^{2+}$ |
| $2H^+$ | $\leftrightarrows H_2$ |

$KI + H_2SO_{4(conc.)} \rightarrow$

| $2I^-$ | $\leftrightarrows I_2$ |
| $SO_4^{2-}$ | $\leftrightarrows H_2S$ |

$KI + K_2SO_3 + H_2SO_4 \rightarrow$

| $2I^-$ | $\leftrightarrows I_2$ |
| $SO_3^{2-}$ | $\leftrightarrows S$ |

$Cu + H_2SO_{4(conc.)} \rightarrow$

| Cu | $\leftrightarrows Cu^{2+}$ |
| $SO_4^{2-}$ | $\leftrightarrows SO_2$ |

$HCl + H_2SeO_{4(conc.)} \rightarrow$

| $2Cl^-$ | $\leftrightarrows Cl_2$ |
| $SeO_4^{2-}$ | $\leftrightarrows SeO_2$ |
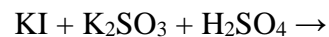
7. Write the ionic and molecular reactions, the qualitative identification of ions:

| Ions | Molecular reactions | Net ionic equation |
|---|---|---|
| $S^{2-}$ | | |
| $SO_3^{2-}$ | | |
| $SO_4^{2-}$ | | |
| $SO_3S^{2-}$ | | |

*Laboratory Work*

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 1.**<br>**Oxidation-reduction properties**<br>**of hydrogen peroxide**<br>   a) Place into a test-tube two-three drops of 0.1 $N$ potassium iodide solution and one drop of 2 N sulphuric acid solution. Add, in drops, hydrogen peroxide solution. Note the shift of the color of the solution. Write the reaction equation. Select the coefficients by half-reaction method. | | | |
|    b) To two-three drops of 0.1 $N$ potassium permanganate solution acidified with one drop of 2 $N$ sulphuric acid solution, add, in drops, hydrogen peroxide solution till the violet color of the solution disappears. Write the reaction equation. Select the coefficients by half-reaction method. Draw a conclusion as to the oxidation-reduction properties of hydrogen peroxide. | | | |
| **Experiment 2.**<br>**Reaction of qualitative identification**<br>**of hydrogen peroxide**<br>   Place three-four drops of hydrogen peroxide solution and three-four drops of 2 $N$ sulphuric acid solution into a test-tube. Add four-five drops of ether and two-three drops of 0.5 $N$ potassium dichromate solution. Stir the solution and let it settle until the formation of two layers. Notice the blue coloration of the ether layer due to the formation of chromium oxidediperoxide $CrO_5$. Write the reaction equations. Give the graphic formula of $CrO_5$. | | | |

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 3.** <br> **Thiosulphuric acid and thiosulphates** <br> a) Place five-six drops of 0.5 $N$ sodium thiosulfate solution into a test-tube and add three-four drops of 2 $N$ sulphuric acid solution. Note the formation of precipitate and gassing. Write the reaction equations. Give the graphic formula of thiosulphuric acid. | | | |
| b) To a test-tube with five-six drops of sodium thiosulphate add, in drops, chlorine or bromine water till the sulphur precipitates. Write the equation of oxidation-reduction reaction, which occurs with insufficient amount of an oxidizing agent. | | $Na_2SO_3S + Br_{2(lack)} + H_2O \rightarrow$ <br><br> $SO_3S^{2-} \leftrightarrows S^0 + SO_4^{2-}$ <br><br> $Br_2^0 \leftrightarrows 2Br^-$ | |
| c) To a test-tube with three-four drops of bromine water add, in drops, sodium thiosulphate solution till the bromine water is completely discoloured. Write the equation of oxidation-reduction reaction, which occurs, with the excess of an oxidizing agent. | | $Na_2SO_3S + Cl_{2(excess.)} + H_2O \rightarrow$ <br><br> $SO_3S^{2-} \leftrightarrows SO_4^{2-}$ <br><br> $Cl_2^0 \leftrightarrows 2Cl^-$ | |
| d) To five-six drops of iodine water (KI + I$_2$) add, in drops, 0.5 $N$ sodium thiosulphate solution until the iodine water is completely discoloured. Write the reaction equation. Calculate the equivalent mass of sodium thiosulphate in the reaction referred. Give the graphic formula of sodium tetrathionate. | | | |

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 4.** <br> **Qualitative identification of sulphate-ion** <br> To two-three drops of 0.1 $N$ sodium sulphate solution add the same amount of diluted hydrochloric acid and 0.1 $N$ barium chloride solution. Indicate the colour of the precipitate. Write the reaction equation in molecular and ionic forms. | | | |

## *The example of control-test*

1. Write the electron formula of Sulphur atom. Indicate valence atoms and possible oxidation numbers for Sulphur in different compounds.
2. Write graphic formulas of sodium thiosulfate.
3. Complete the reaction equations, select the coefficients by electron-ionic method: $H_2O_2 + KMnO_4 + H_2SO_4 \rightarrow$
4. Write the reaction equations for dissociation of $H_2S$ and $H_2SO_3$.
5. Write the reaction equation for disproportionation of hydrogen peroxide.

# LESSON № ___

## Topic: *p*-ELEMENTS OF VIIA GROUP

*Theoretical issues*

General characteristics of VIIA group elements. Physical and chemical properties of Fluorine, Chlorine, Bromine, Iodine and their compounds. Halogen compounds with hydrogen, their solubility in water. Shifting of acidic properties in HF – HCl – HBr – HI series. Oxygen containing compounds of halogens. Shifting of acidic properties and oxidizing activity in HClO – HClO$_2$ – HClO$_3$ – HClO$_4$ series. Bleaching powder.

Reaction of qualitative identification of halogenide ions.

Biological role of p-elements of VII group. Application of their compounds in medicine and pharmaceutical analysis.

*Home task*

1. Fill in the table:

| Acids | Name | Name of the salt anion |
|-------|------|------------------------|
| HCl | | |
| HClO | | |
| HClO$_2$ | | |
| HClO$_3$ | | |
| HClO$_4$ | | |

2. Write the reactions of obtaining hydrogen chloride. Give the name of the compounds:

        a) H$_2$ + Cl$_2$ →                      b) PCl$_3$ + H$_2$O →                  c) SiCl$_4$ + H$_2$O →
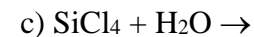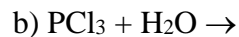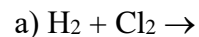
3. Write the reactions of halogens with water. Determine the type of redox reactions:

        F$_2$ +   H$_2$O →                          Cl$_2$ +   H$_2$O →

4. Calculate the mass of sodium chloride are needed to prepare 400 g of solution with mass percent of 0.9%.

5. Calculate the pH of 0.001 *M* solution of perchloric acid (HClO$_4$).

*Test-questions and problems*

1. Fill in the table.

| Elements | Oxidation states | Electron configuration | Examples of compounds |
|---|---|---|---|
| F | 0 | | |
| | -1 | | |
| Cl | -1 | | |
| | 0 | | |
| | +1 | | |
| | +3 | | |
| | +5 | | |
| | +7 | | |

2. Indicate how in the row F – Cl – Br – I – At change:

| Atomic radius | | |
|---|---|---|
| **Electronegativity** | | |
| **Oxidizing activity** | | |
| **Metallic character** | | |
| **Reducing activity** | | |

3. Write the reactions produce chlorine in the laboratory. Select the coefficients by electron-ionic method:

$HCl + PbO_2 \rightarrow$                                        $HCl + KMnO_4 \rightarrow$

$Cl^-$                        $\leftrightarrows Cl_2^0$                $Cl^-$                        $\leftrightarrows Cl_2^0$

$PbO_2$                    $\leftrightarrows Pb^{2+}$            $MnO_4^-$                $\leftrightarrows Mn^{2+}$

4. Explain the reason why the HF acid cannot be stored in glass containers. Write the reactions and name the compounds:

$$SiO_2 + 4HF \rightarrow \qquad\qquad\qquad\qquad SiO_2 + 6HF \rightarrow$$
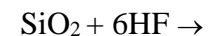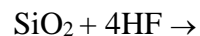
Enter the reason for the association of liquid and gaseous hydrogen fluoride $(HF)_n$:

5. Complete the reaction equations. For the Red-Ox reactions select the coefficients by electron-ionic method and calculate the equivalent mass of an oxidizing and reducing agents.

$$NaCl_{(s)} + H_2SO_{4(conc)} \rightarrow$$

$NaBr_{(s)} + H_2SO_{4(conc)} \rightarrow$ $\qquad\qquad\qquad$ $NaI_{(s)} + H_2SO_{4(conc)} \rightarrow$

$2Br^- \qquad\qquad\qquad \leftrightarrows Br_2^0$ $\qquad\qquad$ $2I^- \qquad\qquad\qquad \leftrightarrows I_2^0$

$SO_4^{2-} \qquad\qquad\qquad \leftrightarrows SO_2$ $\qquad\qquad$ $SO_4^{2-} \qquad\qquad\qquad \leftrightarrows H_2S$

$E_m(H_2SO_4) = \qquad\qquad E_m(NaBr) =$ $\qquad\qquad$ $E_m(H_2SO_4) = \qquad\qquad E_m(NaI) =$

6. Explain the increase in the number of reducing properties: $NaCl \rightarrow NaBr \rightarrow NaI$

7. Complete the reaction equations, select the coefficients by electron-ionic method:

$Br_2 + Cl_2 + H_2O \rightarrow$ $\qquad\qquad\qquad\qquad$ $KI + KIO_3 + H_2SO_4 \rightarrow$

$Br_2^0 \qquad\qquad \leftrightarrows 2BrO_3^-$ $\qquad\qquad\qquad$ $2I^- \qquad\qquad \leftrightarrows I_2$

$Cl_2 \qquad\qquad \leftrightarrows 2Cl^-$ $\qquad\qquad\qquad$ $2IO_3^- \qquad\qquad \leftrightarrows I_2$

$Cl_2 + Ca(OH)_2 \rightarrow$

$Cl_2$             $\leftrightarrows$   $2ClO^-$

$Cl_2$             $\leftrightarrows$   $2Cl^-$
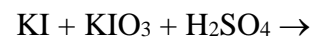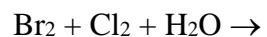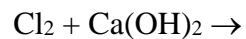
8. Specify the changing in the row of compounds $HClO - HClO_2 - HClO_3 - HClO_4$:

Acidic properties: _____          Oxidizing properties: _____

9. Determine whether it is possible to carry out the reaction by comparing the standard redox potentials of the conjugate pairs:

$HBrO + 2H_2O + 4\bar{e} \leftrightarrows BrO_3^- + 5H^+$    $E^0, V = +1{,}34$
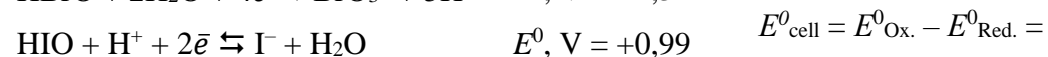
$HIO + H^+ + 2\bar{e} \leftrightarrows I^- + H_2O$          $E^0, V = +0{,}99$      $E^0{}_{cell} = E^0{}_{Ox.} - E^0{}_{Red.} =$

## *The example of control-test*

1. Write the electron configuration of the valence electrons for the atoms of halogens.
2. Select the coefficients by electron-ionic method: $KBr + KBrO_3 + H_2SO_4 \rightarrow Br_2 + K_2SO_4 + H_2O$.
3. Determine the type of redox reaction: $3Br_2^0 + 6NaOH \xrightarrow{t^\circ} 5NaBr + NaBrO_3 + 3H_2O$.
4. Name the following compounds: $NaBr$, $NH_4Cl$, $KI$.
5. Calculate the pH $0.001$ $M$ solution of perchloric acid ($HClO_4$).

*Laboratory Work*

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 1.**<br>**Comparison of the solubility of iodine in water and a solution of potassium iodide**<br>In the test tube add a few crystals of iodine, then add 10 drops of water, stir with a glass stick. Observe the appearance of yellow color of the solution. Add to the test tube a few crystals of potassium iodide and stir with a glass stick. Note the change in color of the solution. Write the reaction with the formation of coordination compound potassium diiodoiodate (I). Explain solubility of iodine in potassium iodide solution. | | | |
| **Experiment 2.**<br>**Qualitative identification of the chloride, bromide and iodide ions**<br>In the three test tubes add 1-2 drops of 0.5 $N$ solutions: first - sodium chloride, the second - potassium bromide, in the third - potassium iodide. In each test tube, add 1-2 drops of 0.1 $N$ solution of silver nitrate to precipitate formation. Specify the color of silver chloride, silver bromide and silver iodide. Write the reactions at the molecular and net ionic form. | | | |
| **Experiment 3.**<br>**Obtaining the oxygen-containing compounds of halogens**<br>In the test tube add a few crystals of iodine. Add dropwise 0.5 $N$ solution of potassium hydroxide and heat gently. Watch the bleaching solution. Then the cooled solution acidified with a few drops of 2 $N$ solution of sulphuric acid. Note the discoloration of the solution. Write the reactions. Specify the type of redox reactions. | | | |

# LESSON № ___

## Topic: *d*-ELEMENTS OF VIB – VIIB GROUPS

### *Theoretical issues*

General characteristics of VIB – VIIB groups elements. Physical and chemical properties of Chromium, Manganese and their compounds.

Oxides and hydroxides of Chromium and Manganese. Chromium (III) oxide and hydroxide, their amphoterism. Solubility of salts in water, their hydrolysis. Complex chromium (III) compounds. Oxidation-reduction properties of chromium (III) compounds. Reaction of qualitative determination of chromium (III) cation. Chromium (VI) compounds. Chromium (VI) oxide. Chromate and dichromates.

Manganese (II) salts, their hydrolysis. Complex compounds of manganese (II). Manganese (VII) compounds. Permanganates. Oxidation properties of potassium permanganate and their dependence on pH of a solution.

Reactions of qualitative identification of Chromium and Manganese compounds.

Biological role of Chromium and Manganese compounds and their application in medicine and pharmaceutical analysis.

### *Home task*

1. Fill in the table: write the electron configuration of the valence electrons for the atoms of Chromium, the possible oxidation states and examples of compounds with the indicated oxidation states.

| Valence electrons | Possible oxidation states | Examples of compounds with the indicated oxidation states |
|---|---|---|
| | | |

2. Specify the direction of change in the acidic properties of chromium oxides in a row: $CrO \rightarrow Cr_2O_3 \rightarrow CrO_3$.

3. Complete the reaction equations, select the coefficients by electron-ionic method:

$$FeSO_4 + K_2Cr_2O_7 + \ H_2SO_4 \rightarrow \ Fe_2(SO_4)_3 \ +$$

4. Write reaction of hydrolysis of chromium (III) sulphate in molecular and ionic forms $Cr_2(SO_4)_3$ on the first step. Enter the pH of the medium.

| Ionic equation of hydrolysis | Molecular equation of hydrolysis | pH |
|---|---|---|
| | | |

5. Fill in the table: write the electron configuration of the valence electrons for the atoms of Manganese, the possible oxidation states and examples of compounds with the indicated oxidation states.

| Valence electrons | Possible oxidation states | Examples of compounds with the indicated oxidation states |
|---|---|---|
| | | |

6. Specify the direction of increasing the acidic properties: $MnO \rightarrow MnO_2 \rightarrow Mn_2O_7$.

7. Using the activity series of metals, complete reaction equation:

$$Mn + \ HCl \rightarrow \qquad\qquad\qquad Mn + ZnSO_4 \rightarrow$$

*Test-questions and problems*

1. Write the formula of hydroxides, which are responsible the following oxides:

| Chromium oxides | Chromium hydroxides |
|---|---|
| CrO | |
| $Cr_2O_3$ | |
| $CrO_3$ | |

2. With the help of chemical reactions prove amphoteric properties of chromium (III) hydroxide.

3. Explain why, when mixed solutions of chromium (III) sulfate $Cr_2(SO_4)_3$ and sodium sulfide $Na_2S$ precipitate $Cr(OH)_3$ is formed. Response to confirm the appropriate molecular and ionic the reaction equation.

| Ionic equation of hydrolysis | Molecular equation of hydrolysis |
|---|---|
|  |  |

4. Calculate the solubility of $BaCrO_4$ at 25 ºC in the unit mol/L. $K_{SP}$ $BaCrO_4 = 1.6 \times 10^{-10}$.

5. Complete the reaction equations, select the coefficients by electron-ionic method:

$K_3[Cr(OH)_6] + H_2O_2 \rightarrow$                    $Na_2S + K_2CrO_4 + H_2O \rightarrow$

$[Cr(OH)_6]^{3-}$    $\leftrightarrows CrO_4^{2-}$              $S^{2-}$    $\leftrightarrows S^0$

$H_2O_2$    $\leftrightarrows 2OH^-$              $CrO_4^{2-}$    $\leftrightarrows [Cr(OH)_6]^{3-}$

$H_2O_2 + K_2Cr_2O_7 + H_2SO_4 \rightarrow$

$H_2O_2$    $\leftrightarrows O_2$

$Cr_2O_7^{2-}$    $\leftrightarrows 2Cr^{3+}$
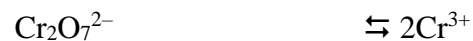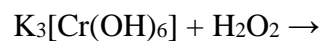
6. Complete the reaction, which characterizes the reduction properties of Mn (II) compounds, select the coefficients by electron-ionic method. This is the reaction of qualitative identification of manganese (II) cation.

$$MnSO_4 + NaBiO_3 + HNO_3 \xrightarrow{t°}$$

$Mn^{2+}$              $\leftrightarrows MnO_4^-$

$BiO_3^-$              $\leftrightarrows Bi^{3+}$
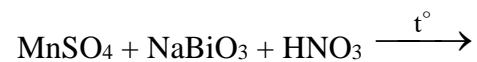
7. Complete the reaction equation describing the oxidation properties of $KMnO_4$, depending on the reaction of the medium and select the coefficients by electron-ionic method:

$KNO_2 + KMnO_4 + H_2SO_4 \rightarrow$  $\qquad\qquad\qquad\qquad$  $KNO_2 + KMnO_4 + H_2O \rightarrow$

$\qquad$ $HNO_2$ $\qquad\qquad$ $\leftrightarrows NO_3^-$  $\qquad\qquad\qquad$ $NO_2^-$ $\qquad\qquad$ $\leftrightarrows NO_3^-$

$\qquad$ $MnO_4^-$ $\qquad\qquad$ $\leftrightarrows Mn^{2+}$  $\qquad\qquad\qquad$ $MnO_4^-$ $\qquad\qquad$ $\leftrightarrows MnO_2$

$KNO_2 + KMnO_4 + KOH \rightarrow$

$\qquad$ $NO_2^-$ $\qquad\qquad$ $\leftrightarrows NO_3^-$

$\qquad$ $MnO_4^-$ $\qquad\qquad$ $\leftrightarrows MnO_4^{2-}$
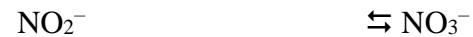
8. Calculate the mass of potassium permanganate necessary to oxidize 4.56 g of iron (II) sulphate in acid medium.

9. Write reaction of hydrolysis of manganese (II) sulphate in molecular and ionic forms on the first step. Enter the pH of the medium.

| Ionic equation of hydrolysis | Molecular equation of hydrolysis | pH |
|---|---|---|
|  |  |  |

## Laboratory Work

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 1.**<br><br>**Obtaining chromium (III) oxide and study of its properties (Draught!)**<br><br>Place three-four microspatulas ammonium dichromate $(NH_4)_2Cr_2O_7$ into a porcelain cup, add three-four drops of ethyl alcohol, and ignite them. Note the changes taking place. Study the interaction between the obtained $Cr_2O_3$ and acids and alkalis. Write the equations for the corresponding reactions. | | | |
| **Experiment 2.**<br><br>**Oxidation of chromium (III) compounds with hydrogen peroxide in alkaline medium**<br><br>Produce sodium hexahydroxochromate (III) solution, add to it three-five drops of 3% hydrogen peroxide solution, by mass. Heat the mixture until the green solution turns yellow. Write the equation for oxidation of $Na_3[Cr(OH)_6]$ with hydrogen peroxide.<br><br>This is the reaction of qualitative identification of chromium (III) cation. | | | |
| **Experiment 3.**<br><br>**Change of chromate to dichromate**<br><br>Place three-four drops of 0.5 $N$ potassium chromate solution into a test-tube. Note the coloration typical of chromic ion. Add one-two drops of 2 $N$ sulphuric acid solution. Note the coloration of the solution obtained due to the presence of dichromate-ions. To the obtained solution add 2 $N$ sodium hydroxide solution, in drops, till the shifting of the colour of the precipitate. Write ionic and molecular reaction equations for the change of chromate to dichromate and back. | | | |

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 4** <br> **Reduction properties** <br> **of manganese(II)compounds** <br> Place 1 microspatula of lead (IV) peroxide into a test-tube. Add three-four drops of concentrated nitric acid and one drop of 0.5 $N$ manganese (II) salt solution. Heat the contents of the test-tube. Note the coloration of the solution. Write the reaction equation; select the coefficients by electron-ionic method. <br> This is the reaction of qualitative identification of manganese (II) cation. | | | |

### *The example of control-test*

1. Describe shifting in acid-basic properties in the following series: $MnO \rightarrow Mn_2O_3 \rightarrow MnO_2 \rightarrow MnO_3 \rightarrow Mn_2O_7$. Write the formulae of corresponding hydroxides and name them according to traditional nomenclature.
2. Characterize shifting in acid-basic properties of chromium oxides/hydroxides when shifting from lower oxidation numbers to higher.
3. Explain why mixing of chromium (III) sulphate and sodium sulphide solutions leads to precipitation of $Cr(OH)_3$. Prove your opinion with corresponding ionic and molecular reaction equations.
4. Using electrochemical series of metals write equations for the reactions occurring:

$$Mn + HCl \rightarrow \qquad Mn + ZnSO_4 \rightarrow \qquad Mn + Al_2(SO_4)_3 \rightarrow$$

5. Complete the reaction equations, select the coefficients by electron-ionic method:

$$FeSO_4 + K_2Cr_2O_7 + H_2SO_4 \rightarrow \qquad (NH_4)_2S + K_2Cr_2O_7 + H_2SO_4 \rightarrow \qquad K_3[Cr(OH)_6] + H_2O_2 \rightarrow$$

# LESSON № ___

## Topic: *d*-ELEMENTS OF VIIIB, IB – IIB GROUPS

### *Theoretical issues*

General characteristics of VIIIB group elements. Physical and chemical properties of Iron, Cobalt, Nickel and their compounds. Oxides and hydroxides of Iron triad elements. Iron (II) and iron (III) complex compounds with cyanide- and thiocyanate-ions. Coordination compounds of Cobalt (0), (II) and (III). Nickel (II) complex compounds.

General characteristics of the elements of Copper subgroup. Chemical activity of simple substances. Possible oxidation numbers of copper, silver, and gold in compounds. Copper. Copper (II) oxide and hydroxide. Hydrolysis of copper (I) and copper (II) salts. Copper (II) compounds oxidation activity. Copper (II) complex compounds. Silver. Silver (I) oxide and its properties. Oxidation properties of silver compounds. Solubility of silver salts in water. Gold. Gold (I) and gold (III) compounds.

General characteristics of IIB group elements. Physical and chemical properties of Zinc, Mercury, Cadmium and their compounds. Zinc. Amphoterism of zinc, its oxide, and hydroxide. Zinc coordination compounds with ammonia, water, and alkalis. Hydrolysis of zinc salts. Mercury. Bonding of mercuric atoms. Activity of mercury in diluted and concentrated acids. Mercuric oxides, their obtaining and properties. Disproportionation of compounds of mercury (I) and oxidation properties of mercury (II). Mercury (I) and mercury (II) coordination compounds with halogenide-ions and ammonia. Hydrolysis of salts of mercury (I) and mercury (II).

Reactions of qualitative identification of iron (II) and iron (III) cations.

Biological role of *d*-elements of VIIIB, IB – IIB groups. Application of their compounds in medicine and pharmaceutical analysis.

### *Home task*

1. Using the activity series of metals, complete reaction equation:

$$Fe + HCl \rightarrow \qquad\qquad\qquad\qquad Fe + Cu(NO_2)_3 \rightarrow$$

$$Cu + FeSO_4 \rightarrow$$
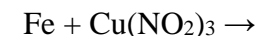
2. Write reaction of hydrolysis of iron(II) sulphate in molecular and ionic forms on the first step. Enter the pH of the medium.

| Ionic equation of hydrolysis | Molecular equation of hydrolysis | pH |
|---|---|---|
|  |  |  |

3. Complete reaction equations, select coefficients by electron-ionic method:

$FeSO_4 + KMnO_4 + H_2SO_4 \rightarrow$  $\qquad$  $Fe(OH)_2 + O_2 + H_2O \rightarrow$

$\qquad$ $2Fe^{2+}$ $\qquad$ $\leftrightarrows 2Fe^{3+}$  $\qquad$  $Fe(OH)_2$ $\qquad$ $\leftrightarrows Fe(OH)_3$

$\qquad$ $MnO_4^-$ $\qquad$ $\leftrightarrows Mn^{2+}$  $\qquad$  $O_2$ $\qquad$ $\leftrightarrows OH^-$

$Co(OH)_2 + H_2O_2 \rightarrow$  $\qquad$  $Fe(OH)_3 + Br_2 + KOH \rightarrow$

$\qquad$ $Co(OH)_2$ $\qquad$ $\leftrightarrows Co(OH)_3$  $\qquad$  $Fe(OH)_3$ $\qquad$ $\leftrightarrows FeO_4^{2-}$

$\qquad$ $H_2O_2$ $\qquad$ $\leftrightarrows 2OH^-$  $\qquad$  $Br_2$ $\qquad$ $\leftrightarrows 2Br^-$
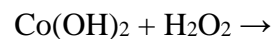
4. Write the formula of oxides and hydroxides of copper, silver, gold, and indicate their properties (basic, acidic or amphoteric)

| Elements | Formula of oxides, their names and properties | Formula of hydroxides, their names and properties |
|---|---|---|
| Cu | | |
| Ag | | |
| Au | | |

5. Write the reaction and name the coordination compound formed (the coordination number of $Au^{+1}$ is equal 2. Select the coefficients by electron-ionic method:

$$Au + O_2 + H_2O + KCN \rightarrow$$

$\qquad$ $Au$ $\qquad$ $\leftrightarrows [Au(CN)_2]^-$

$\qquad$ $O_2$ $\qquad$ $\leftrightarrows OH^-$
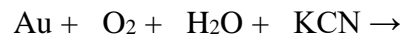
6. Write the hydrolysis equations of $ZnSO_4$:

## *Test-questions and problems*

1. Indicate the most characteristic coordination number of Iron (II), Iron (III), Cobalt (II), Nickel (II) in coordination compounds. Give appropriate examples of compounds:

| Ions | Coordination number | Examples of compounds |
|------|---------------------|----------------------|
| $Fe^{2+}$ | | |
| $Fe^{3+}$ | | |
| $Co^{2+}$ | | |
| $Ni^{2+}$ | | |

2. Write the equation of reactions demonstration the following transformations and name the compounds:

$$FeSO_4 \rightarrow Fe(OH)_2 \rightarrow Fe(OH)_3 \rightarrow Fe_2(SO_4)_3$$
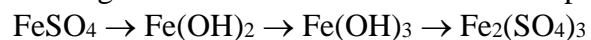
3. Make up reaction equations for the following changes:

a) $Cu \rightarrow CuSO_4 \rightarrow Cu(OH)_2 \rightarrow CuO \rightarrow [Cu(H_2O)_4]SO_4$

b) $Ag \rightarrow AgNO_3 \rightarrow Na_3[Ag(S_2O_3)_2]$
   $\downarrow$
   $Ag$

4. Select the coefficients by electron-ionic method:

Au + $H_2SeO_{4(conc.)} \rightarrow$                                   Au + $HNO_3$ + HCl $\rightarrow$

Au                                  $\leftrightarrows$ $Au^{3+}$                        Au                                  $\leftrightarrows$ $[AuCl_4]^-$

$SeO_4^{2-}$                            $\leftrightarrows$ $SeO_2$                        $NO_3^-$                        $\leftrightarrows$ NO
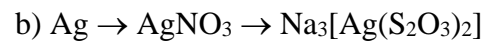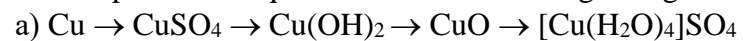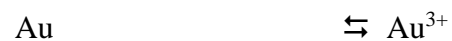
5. With the help of the equations of chemical reactions confirm the amphoteric properties of zinc hydroxide:

$$Zn(OH)_2 + NaOH \rightarrow \qquad\qquad Zn(OH)_2 + HCl \rightarrow$$
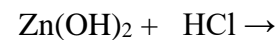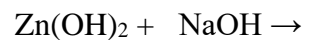
6. Write to the expression of $K_{sp}$ of zinc hydroxide.

7. Write the equation of formation aminocomplex of zinc with coordination number "4":

$$Zn(OH)_2 + NH_3 \rightarrow$$
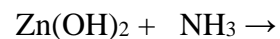
8. Complete the reaction equation:

$$Hg(NO_3)_2 + KOH \rightarrow \qquad\qquad Hg_2(NO_3)_2 + KOH \rightarrow$$
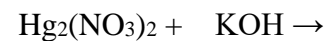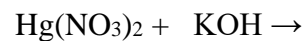
9. Write the primary and secondary equations of dissociation of $K_2[HgI_4]$ and expression of the general instability constants of complex ions.

*Laboratory Work*

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 1.**<br>**Reactions of qualitative identification of ions of iron (II) and iron (III)**<br>a) To three-four drops of freshly produced 0.5 *N* iron (II) sulphate solution add two-three drops of 0.5 *N* potassium hexacyanoferrate (III). Note the coloration of the precipitate. Write ionic and molecular reaction equations. | | | |
| b) Place three-four drops of 0.5 *N* iron (III) solution into a test-tube and add two-three drops of 0.5 *N* potassium hexacyanoferrate (II) solution. Note the coloration of the precipitate. Write ionic and molecular reaction equations. | | | |
| c) Place into a test tube one-two drops of 0.5 *N* iron (III) chloride solution and one drop of 0.01 *N* potassium thiocyanate (KSCN). Note the coloration of the obtained solution. Write ionic and molecular reaction equations. | | | |
| **Experiment 2.**<br>**Iron (II) hydroxide and its properties**<br>Place five-seven drops of freshly produced 0.5 *N* iron (II) sulphate solution into each of 3 test tubes and add several drops of 2 *N* sodium hydroxide solution till the formation of greenish precipitate. Add hydrochloric acid solution to the contents of test-tube 1, and 0.5 *N* sodium hydroxide solution – to test-tube 2. Write ionic and molecular reaction equation. The contents of test-tube 3 stir with a glass stick and leave in the air until the shifting in the colour of precipitate. Explain what is observed. Write the reaction equation for oxidation of iron (II) hydroxide with air oxygen in water medium, select the coefficients using electron-ionic method. | | | |

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 3.** <br> **Obtaining and study of properties** <br> **of cobalt (II) and nickel (II) hydroxides** <br> a) Place five-seven drops of 0.5 $N$ cobalt (II) sulphate solution into each of 2 test tubes and add, in drops, 2 $N$ sodium hydroxide solution till the formation of the precipitate. At first, the precipitate of cobalt basic salt $(CoOH)_2SO_4$, blue by colour, will form. On adding the excess of sodium hydroxide solution, as a result of cobalt (II) hydroxide formation, the solution gains pink color. Add 2 $N$ hydrochloric acid solution to one of test tubes till the dissolving of the precipitate. Add two-three drops of 3% hydrogen peroxide solution, by mass, to another one. Draw a conclusion as to the acid-basic and oxidation-reduction properties of cobalt (II) hydroxide. Write the reaction equations. | | | |
| b) Place five-seven drops of 0.5 $N$ of nickel (II) sulphate solution into each of 3 test tubes and add, in drops, 2 $N$ sodium hydroxide solution until the formation of the precipitate. Note the colour of the precipitate. Add several drops of 2 $N$ hydrochloric acid solution to test-tube 1 until the dissolving of the precipitate. Add two-three drops of 3% hydrogen peroxide solution, by mass, to test-tube 2, and one drop of bromine water – to test-tube 3. Draw a conclusion as to the acid-basic and oxidation-reduction properties of nickel (II) hydroxide. Write the reaction equations. Compare the reduction properties of cobalt (II) and nickel (II) hydroxides. | | | |

| Appellation and brief description of the experiment | Observations | Chemical reaction equations | Conclusions |
|---|---|---|---|
| **Experiment 4.**<br>  **Coordination compounds of mercury (II)**<br>   Place two-three drops of 0.1 *N* mercury (II) nitrate solution into a test-tube and add, in drops, 0.5 *N* potassium iodide solution until the formation of mercury (II) iodide precipitate. Note the colour of the precipitate. Write the reaction equation for mercury (II) iodide production and dissolution leading to the formation of a complex salt. Take into account that the co-ordination number for mercury (II) is "4". | | | |

### *The example of control-test*

1. Write the electron formulae for atoms of zinc, cadmium, and mercury. Indicate possible oxidation numbers of these elements in compounds. Give the examples of compounds with the specified oxidation numbers of the elements.
2. Write ionic and molecular hydrolysis equations for $Co(NO_3)_2$.
3. Complete the reaction equations: $HgCl_2 + NH_{3\,(dilute)} \rightarrow$           $Hg_2Cl_2 + NH_{3(dilute)} \rightarrow$           $Hg(NO_3)_2 + KI_{(exc.)} \rightarrow$
4. Using instability constants of complex ions determine the possibility of interaction of electrolyte solutions: $[Cd(NH_3)_4]Cl_2 + KOH \rightarrow$           $[Cd(NH_3)_4]Cl_2 + KCN \rightarrow$
5. Write the equations for the reactions which occur forming copper (II) complex compounds with coordination number "4".

# APPENDIX

*Table 1*

## Relative molecular masses of some inorganic substances

| | $H^+$ | $NH_4^+$ | $Na^+$ | $K^+$ | $Ba^{2+}$ | $Ca^{2+}$ | $Mg^{2+}$ | $Al^{3+}$ | $Cr^{3+}$ | $Fe^{2+}$ | $Fe^{3+}$ | $Mn^{2+}$ | $Zn^{2+}$ | $Cu^{2+}$ | $Ag^+$ | $Pb^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $O^{2-}$ | | | 62 | 94 | 153 | 56 | 40 | 102 | 152 | 72 | 160 | 71 | 81 | 80 | 232 | 223 |
| $OH^-$ | 18 | 35 | 40 | 56 | 171 | 74 | 58 | 78 | 103 | 90 | 107 | 89 | 99 | 98 | 125 | 241 |
| $Cl^-$ | 36.5 | 53.5 | 58.5 | 74.5 | 208 | 111 | 95 | 133.5 | 158.5 | 127 | 162.5 | 126 | 136 | 135 | 143.5 | 278 |
| $Br^-$ | 81 | 98 | 103 | 119 | 297 | 200 | 184 | 267 | 292 | 216 | 296 | 215 | 225 | 224 | 188 | 367 |
| $I^-$ | 128 | 145 | 150 | 166 | 391 | 294 | 278 | 408 | 433 | 310 | 437 | 309 | 319 | 318 | 235 | 461 |
| $NO_3^-$ | 63 | 80 | 85 | 101 | 261 | 164 | 148 | 213 | 238 | 180 | 242 | 179 | 189 | 188 | 170 | 331 |
| $S^{2-}$ | 34 | 68 | 78 | 110 | 169 | 72 | 56 | 150 | 200 | 88 | 208 | 87 | 97 | 96 | 248 | 239 |
| $SO_3^{2-}$ | 82 | 116 | 126 | 158 | 217 | 120 | 104 | 294 | 344 | 136 | 352 | 135 | 145 | 144 | 294 | 287 |
| $SO_4^{2-}$ | 98 | 132 | 142 | 174 | 233 | 136 | 120 | 342 | 392 | 152 | 400 | 151 | 161 | 160 | 312 | 303 |
| $CO_3^{2-}$ | 62 | 96 | 106 | 138 | 197 | 100 | 84 | 234 | 284 | 116 | 292 | 115 | 125 | 124 | 276 | 267 |
| $SiO_3^{2-}$ | 78 | 112 | 122 | 154 | 213 | 116 | 100 | 282 | 332 | 132 | 340 | 131 | 141 | 140 | 292 | 283 |
| $PO_4^{3-}$ | 98 | 149 | 164 | 212 | 601 | 310 | 262 | 122 | 147 | 358 | 151 | 355 | 385 | 382 | 419 | 811 |

*Table 2*

## Density of sodium chloride solutions in aqueous solutions at 20 ºC

| Sodium chloride proportion in solution, by mass, % | Density, g/mL | Sodium chloride proportion in solution, by mass, % | Density, g/mL |
|---|---|---|---|
| 2 | 1.013 | 14 | 1.101 |
| 4 | 1.027 | 16 | 1.116 |
| 6 | 1.041 | 18 | 1.132 |
| 8 | 1.056 | 20 | 1.148 |
| 10 | 1.071 | 22 | 1.164 |
| 12 | 1.086 | 24 | 1.180 |

*Table 3*

**Ionization energies and electron affinity of atoms of some elements**

| Element | Ionization energies, eV | | | Electron affinity, eV |
|---------|-------|-------|-------|------------------------|
| | $I_1$ | $I_2$ | $I_3$ | |
| H | 13.60 | – | – | 0.75 |
| He | 24.59 | 54.42 | – | -0.22 |
| Li | 5.39 | 75.64 | 122.42 | 0.59 |
| Be | 9.32 | 18.21 | 153.90 | -0.19 |
| B | 8.30 | 25.16 | 37.93 | 0.30 |
| C | 11.26 | 24.38 | 47.88 | 1.27 |
| N | 14.53 | 29.60 | 47.45 | -0.21 |
| O | 13.62 | 35.12 | 54.90 | 1.47 |
| F | 17.42 | 34.99 | 62.66 | 3.45 |
| Ne | 21.56 | 41.08 | 63.00 | -0.22 |
| Na | 5.14 | 47.30 | 71.65 | 0.34 |
| Mg | 7.65 | 15.04 | 80.14 | -0.22 |
| Cl | 12.97 | 23.80 | 39.91 | 3.61 |
| K | 4.34 | 31.82 | 46.00 | 0.47 |
| Br | – | – | – | 3.37 |
| I | – | – | – | 3.08 |

*Table 4*

## Relative electronegativities of some elements

|  | I | II | III | IV | V | VI | VII | VIII | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **I** | **H** 2.1 | | | | | | | | | | **He** |
| **II** | **Li** 1.0 | **Be** 1.5 | **B** 2.0 | **C** 2.5 | **N** 3.0 | **O** 3.5 | **F** 4.0 | | | | **Ne** |
| **III** | **Na** 0.9 | **Mg** 1.2 | **Al** 1.5 | **Si** 1.8 | **P** 2.1 | **S** 2.5 | **Cl** 3.0 | | | | **Ar** |
| **IV** | **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** 1.8 | **Ni** 1.8 | |
| | **Cu** 1.9 | **Zn** 1.6 | **Ga** 1.6 | **Ge** 1.8 | **As** 2.0 | **Se** 2.4 | **Br** 2.8 | | | | **Kr** |
| **V** | **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** |
| **VI** | **Cs** 0.7 | **Ba** 0.9 | **La** 1.1 | **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 | **Ti** 1.8 | **Pb** 1.8 | **Bi** 1.9 | **Po** 2.0 | **At** 2.2 | | | | **Rn** |
| **VII** | **Fr** 0.7 | **Ra** 0.9 | **Ac** 1.1 | | | | | | | | |

*Table 5*

**Solubility of salts, acids and bases in aqueous solutions**

| Anion \ Cation | $H^+$ | $NH_4^+$ | $K^+$ | $Na^+$ | $Mg^{2+}$ | $Ca^{2+}$ | $Ba^{2+}$ | $Al^{3+}$ | $Cr^{3+}$ | $Zn^{2+}$ | $Mn^{2+}$ | $Fe^{2+}$ | $Fe^{3+}$ | $Hg^{2+}$ | $Cu^{2+}$ | $Ag^+$ | $Pb^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $OH^-$ | – | S | S | S | SS | SS | S | I | I | I | I | I | I | – | I | – | I |
| $F^-$ | S | S | S | S | SS | I | SS | SS | SS | SS | S | SS | SS | S | S | S | I |
| $Cl^-$ | S | S | S | S | S | S | S | S | S | S | S | S | S | S | S | I | SS |
| $Br^-$ | S | S | S | S | S | S | S | S | S | S | S | S | S | SS | S | I | SS |
| $I^-$ | S | S | S | S | S | S | S | S | S | S | S | S | – | I | – | I | I |
| $S^{2-}$ | S | S | S | S | I | I | S | – | – | I | I | I | I | I | I | I | I |
| $SO_3^{2-}$ | S | S | S | S | S | SS | SS | – | – | SS | I | SS | – | – | – | SS | I |
| $SO_4^{2-}$ | S | S | S | S | S | SS | I | S | S | S | S | S | S | – | S | SS | SS |
| $NO_3^-$ | S | S | S | S | S | S | S | S | S | S | S | S | S | S | S | S | S |
| $PO_4^{3-}$ | S | S | S | S | I | I | I | I | I | I | I | I | I | I | I | I | I |
| $CO_3^{2-}$ | S | S | S | S | I | I | I | – | – | I | I | I | – | I | – | I | I |
| $SiO_3^{2-}$ | I | – | S | S | I | I | I | I | I | I | I | I | I | – | I | I | I |
| $CH_3COO^-$ | S | S | S | S | S | S | S | S | S | S | S | S | S | – | S | S | S |

s – soluble ( >1g in 100 g of water);
ss – slightly soluble(0.001 g – 1 g in 100 g of water);

I – insoluble (< 0.001 g – 1 g in 100 g of water);
– – decomposes in water or does not exist.

*Table 6*

## Constants of dissociation of acids and bases in aqueous solutions, at 25 ºC

| Acid | Formula | Acid dissociation constant ($K_a$) | | $pK_a = -\lg K_a$ | Base | Formula | Base dissociation constant ($K_B$) | | $pK_B = -\lg K_B$ |
|---|---|---|---|---|---|---|---|---|---|
| Acetic | $CH_3COOH$ | | $1.8 \times 10^{-5}$ | 4.75 | Aluminium hydroxide | $Al(OH)_3$ | $K_3$ | $1.4 \times 10^{-9}$ | 8.86 |
| Boric (meta-) | $HBO_2$ | | $7.5 \times 10^{-10}$ | 9.12 | Ammonium (solution) | $NH_3 \cdot H_2O$ | | $1.8 \times 10^{-5}$ | 4.75 |
| Boric (ortho-) | $H_3BO_3$ | $K_1$ | $5.8 \times 10^{-10}$ | 9.24 | Barium hydroxide | $Ba(OH)_2$ | $K_2$ | $2.3 \times 10^{-1}$ | 0.64 |
| Boric (tetra-) | $H_2B_4O_7$ | $K_1$ | $5.8 \times 10^{-4}$ | 3.74 | Calcium hydroxide | $Ca(OH)_2$ | $K_2$ | $4.0 \times 10^{-2}$ | 1.40 |
| | | $K_2$ | $2.0 \times 10^{-8}$ | 7.70 | Chromium (III)hydroxide | $Cr(OH)_3$ | $K_3$ | $1.02 \times 10^{-10}$ | 9.99 |
| Carbonic | $H_2CO_3$ | $K_1$ | $4.5 \times 10^{-7}$ | 6.35 | Copper (II) hydroxide | $Cu(OH)_2$ | $K_2$ | $3.4 \times 10^{-7}$ | 6.47 |
| | | $K_2$ | $4.7 \times 10^{-11}$ | 10.33 | Hydrazine (solution) | $N_2H_4 \cdot H_2O$ | | $9.3 \times 10^{-7}$ | 6.03 |
| Formic | $HCOOH$ | | $1.8 \times 10^{-4}$ | 3.74 | Iron (II) hydroxide | $Fe(OH)_2$ | $K_2$ | $1.3 \times 10^{-4}$ | 3.89 |
| Hypochlorous | $HClO$ | | $5.0 \times 10^{-8}$ | 7.30 | Iron (III) hydroxide | $Fe(OH)_3$ | $K_2$ | $1.8 \times 10^{-11}$ | 10.74 |
| Hydrocyanic | $HCN$ | | $7.9 \times 10^{-10}$ | 9.10 | | | $K_3$ | $1.35 \times 10^{-12}$ | 11.87 |
| Hydrogen peroxide | $H_2O_2$ | $K_1$ | $2.6 \times 10^{-12}$ | 11.58 | Lead (II) hydroxide | $Pb(OH)_2$ | $K_1$ | $9.55 \times 10^{-4}$ | 3.02 |
| Hydrosulphuric | $H_2S$ | $K_1$ | $6 \times 10^{-8}$ | 7.22 | | | $K_2$ | $3.0 \times 10^{-8}$ | 7.52 |
| | | $K_2$ | $1 \times 10^{-14}$ | 14.00 | Magnesium hydroxide | $Mg(OH)_2$ | $K_2$ | $2.5 \times 10^{-3}$ | 2.60 |
| Hypobromous | $HBrO$ | | $2.1 \times 10^{-9}$ | 8.68 | Silver (I) hydroxide | $AgOH$ | | $5.0 \times 10^{-3}$ | 2.30 |
| Nitrous | $HNO_2$ | | $4 \times 10^{-4}$ | 4.59 | Water | $H_2O$ | | $1.8 \times 10^{-16}$ | 15.76 |
| Oxalic | $H_2C_2O_4$ | $K_1$ | $5.4 \times 10^{-2}$ | 1.27 | Zinc hydroxide | $Zn(OH)_2$ | $K_2$ | $4 \times 10^{-5}$ | 4.4 |
| Phosphoric (ortho-) | $H_3PO_4$ | $K_1$ | $7.5 \times 10^{-3}$ | 2.12 | | | | | |
| | | $K_2$ | $6.3 \times 10^{-8}$ | 7.20 | | | | | |
| | | $K_3$ | $1.3 \times 10^{-12}$ | 11.89 | | | | | |
| Silicic (meta-) | $H_2SiO_3$ | $K_1$ | $2.2 \times 10^{-10}$ | 9.66 | | | | | |
| | | $K_2$ | $1.6 \times 10^{-12}$ | 11.80 | | | | | |
| Sulphurous | $H_2SO_3$ | $K_1$ | $1.6 \times 10^{-2}$ | 1.80 | | | | | |
| | | $K_2$ | $6.3 \times 10^{-8}$ | 7.21 | | | | | |

**Solubility product of slightly soluble electrolytes at 25 ºC**

| Substance | Solubility product (SP) | Substance | Solubility product (SP) |
|---|---|---|---|
| AgBr | $6\times10^{-13}$ | CdS | $7.9\times10^{-27}$ |
| AgCl | $1.8\times10^{-10}$ | $Cu(OH)_2$ | $2.2\times10^{-20}$ |
| $Ag_2CrO_4$ | $4\times10^{-12}$ | CuS | $6\times10^{-36}$ |
| AgI | $1.1\times10^{-16}$ | $Fe(OH)_2$ | $1\times10^{-15}$ |
| $Ag_2S$ | $6\times10^{-50}$ | $Fe(OH)_3$ | $3.8\times10^{-38}$ |
| $BaCO_3$ | $5\times10^{-9}$ | FeS | $5\times10^{-18}$ |
| $BaCrO_4$ | $1.6\times10^{-10}$ | HgS | $1.6\times10^{-52}$ |
| $BaSO_4$ | $1.1\times10^{-10}$ | MnS | $2.5\times10^{-10}$ |
| $CaCO_3$ | $5\times10^{-9}$ | PbS | $1\times10^{-27}$ |
| $CaC_2O_4$ | $2\times10^{-9}$ | SnS | $1\times10^{-24}$ |
| $CaSO_4$ | $1.3\times10^{-10}$ | $Zn(OH)_2$ | $1\times10^{-17}$ |
| $Cd(OH)_2$ | $2\times10^{-14}$ | ZnS | $1.6\times10^{-24}$ |

*Table 8*

**The Activity Series of Metals**

| | Li | K | Ca | Na | Mg | Al | Mn | Zn | Cr | Fe | Cd | Co |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Me^{z+}/Me$ | $Li^+/Li$ | $K^+/K$ | $Ca^{2+}/Ca$ | $Na^+/Na$ | $Mg^{2+}/Mg$ | $Al^{3+}/Al$ | $Mn^{2+}/Mn$ | $Zn^{2+}/Zn$ | $Cr^{3+}/Cr$ | $Fe^{2+}/Fe$ | $Cd^{2+}/Cd$ | $Co^{2+}/Co$ |
| $E^o$, V | $-3.04$ | $-2.93$ | $-2.87$ | $-2.71$ | $-2.36$ | $-1.67$ | $-1.18$ | $-0.76$ | $-0.74$ | $-0.44$ | $-0.40$ | $-0.28$ |

| | Ni | Mo | Sn | Pb | **H** | Bi | Cu | Ag | Hg | Pt | Au |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Ni^{2+}/Ni$ | $Mo^{3+}/Mo$ | $Sn^{2+}/Sn$ | $Pb^{2+}/Pb$ | $2H^+/H_2$ | $Bi^{3+}/Bi$ | $Cu^{2+}/Cu$ | $Ag^+/Ag$ | $Hg^{2+}/Hg$ | $Pt^{2+}/Pt$ | $Au^{3+}/Au$ |
| | $-0.25$ | $-0.20$ | $-0.14$ | $-0.13$ | $0.00$ | $0.22$ | $0.34$ | $0.80$ | $0.85$ | $1.19$ | $1.50$ |

*Table 9*

## Oxidation number of elements

| Periods | s-elements | | d-elements | | | | | | | | | | p-elements | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $s^1$ | $s^2$ | $d^1$ | $d^2$ | $d^3$ | $d^4$ | $d^5$ | $d^6$ | $d^7$ | $d^8$ | $d^9$ | $d^{10}$ | $p^1$ | $p^2$ | $p^3$ | $p^4$ | $p^5$ | $p^6$ |
| 1 | **H**<br>+1<br>0<br>−1 | **He**<br>0 | | | | | | | | | | | | | | | **(H)** | **(He)** |
| 2 | **Li**<br>+1<br>0 | **Be**<br>+2<br>0 | | | | | | | | | | | **B**<br>+3<br>0<br>−3 | **C**<br>+4<br>+2<br>0<br>**−4** | **N**<br>+5<br>+4<br>+3<br>+2<br>+1<br>0<br>−1<br>−2<br>−3 | **O**<br>+4<br>+2<br>0<br>−1<br>**−2** | **F**<br>0<br>−1 | **Ne**<br>0 |
| 3 | **Na**<br>+1<br>0 | **Mg**<br>+2<br>0 | | | | | | | | | | | **Al**<br>+3<br>0 | **Si**<br>**+4**<br>+2<br>0<br>**−4** | **P**<br>**+5**<br>+4<br>+3<br>+1<br>0<br>−3 | **S**<br>**+6**<br>+4<br>+2<br>0<br>**−2** | **Cl**<br>+7<br>+6<br>+5<br>+4<br>+3<br>+1<br>0<br>**−1** | **Ar**<br>0 |
| 4 | **K**<br>+1<br>0 | **Ca**<br>+2<br>0 | **Sc**<br>+3<br>0 | **Ti**<br>**+4**<br>+3<br>+2<br>0 | **V**<br>**+5**<br>+4<br>+3<br>+2<br>0 | **Cr**<br>+6<br>**+3**<br>+2<br>0 | **Mn**<br>+7<br>+6<br>**+4**<br>+3<br>**+2**<br>0 | **Fe**<br>+6<br>**+3**<br>+2<br>0 | **Co**<br>+3<br>**+2**<br>0 | **Ni**<br>+4<br>+3<br>**+2**<br>0 | **Cu**<br>+3<br>**+2**<br>+1<br>0 | **Zn**<br>+2<br>0 | **Ga**<br>**+3**<br>+2<br>+1<br>0 | **Ge**<br>**+4**<br>+2 | **As**<br>**+5**<br>+3<br>0<br>−3 | **Se**<br>+6<br>**+4**<br>+2<br>0<br>**−2** | **Br**<br>+7<br>+5<br>+3<br>+1<br>0<br>**−1** | **Kr**<br>0 |
| 5 | **Rb**<br>+1<br>0 | **Sr**<br>+2<br>0 | **Y**<br>+3<br>0 | **Zr**<br>**+4**<br>+3<br>+2<br>0 | **Nb**<br>**+5**<br>+4<br>+3<br>+2<br>+1<br>0 | **Mo**<br>**+6**<br>+5<br>+4<br>+3<br>+2<br>0 | **Tc**<br>**+7**<br>+6<br>+4<br>+2<br>0 | **Ru**<br>**+8**<br>+6<br>**+4**<br>+3<br>+2<br>0 | **Rh**<br>+6<br>+4<br>**+3**<br>+2<br>0 | **Pd**<br>+4<br>**+2**<br>0 | **Ag**<br>+3<br>+2<br>**+1**<br>0 | **Cd**<br>+2<br>0 | **In**<br>**+3**<br>+2<br>+1<br>0 | **Sn**<br>**+4**<br>+2<br>0 | **Sb**<br>+5<br>**+3**<br>0<br>−3 | **Te**<br>+6<br>+4<br>+2<br>0<br>−2 | **I**<br>+7<br>+5<br>+4<br>+1<br>0<br>**−1** | **Xe**<br>0 |
| 6 | **Cs**<br>+1<br>0 | **Ba**<br>+2<br>0 | **La***<br>+4<br>+3<br>+2<br>0 | **Hf**<br>**+4**<br>+3<br>+2<br>0 | **Ta**<br>+5<br>+4<br>+3<br>+2<br>+1<br>0 | **W**<br>**+6**<br>+5<br>+4<br>+3<br>+2<br>0 | **Re**<br>+7<br>+6<br>+4<br>+3<br>+2<br>0 | **Os**<br>**+8**<br>+6<br>**+4**<br>+3<br>+2<br>0 | **Ir**<br>+6<br>**+4**<br>+3<br>0 | **Pt**<br>+6<br>**+4**<br>+2<br>0 | **Au**<br>+3<br>+1<br>0 | **Hg**<br>**+2**<br>+1<br>0 | **Tl**<br>+3<br>**+1**<br>0 | **Pb**<br>+4<br>**+2**<br>0 | **Bi**<br>+5<br>**+3**<br>0<br>−3 | **Po**<br>+4<br>**+2**<br>0<br>−2 | **At**<br>+7<br>+5<br>+3<br>+1<br>0<br>**−1** | **Ra**<br>0 |
| 7 | **Fr**<br>+1<br>0 | **Ra**<br>+2<br>0 | **Ac***<br>+3<br>0 | | | | | | | | | | | | | | | |

– bold face font is select the most characteristic oxidation number of elements

*Table10*

**Standard electrode potentials of certain systems in aqueous solutions**

| Element | Process equation | $E^o$, V |
|---|---|---|
| Aluminium | $[Al(OH)_6]^{3-} + 3\bar{e} \leftrightarrows Al + 6OH^-$ | −2.31 |
| | $Al^{3+} + 3\bar{e} \leftrightarrows Al$ | −1.66 |
| Arsenic | $AsO_4{}^{3-} + 2H_2O + 2\bar{e} \leftrightarrows AsO_2{}^- + 4OH^-$ | −0.67 |
| | $H_3AsO_4 + 2H^+ + 2\bar{e} \leftrightarrows HAsO_2 + 2H_2O$ | 0.56 |
| Bismuth | $Bi(OH)_3 + 3\bar{e} \leftrightarrows Bi + 3OH^-$ | −0.46 |
| Bromine | $BrO^- + H_2O + 2\bar{e} \leftrightarrows Br^- + 2OH^-$ | 0.76 |
| | $Br_2 + 2\bar{e} \leftrightarrows 2Br^-$ | 1.065 |
| | $BrO_3{}^- + 6H^+ + 6\bar{e} \leftrightarrows Br^- + 3H_2O$ | 1.44 |
| | $2BrO_3{}^- + 12H^+ + 10\bar{e} \leftrightarrows Br_2 + 6H_2O$ | 1.52 |
| Chlorine | $2ClO^- + 2H_2O + 2\bar{e} \leftrightarrows Cl_2 + 4OH^-$ | 0.4 |
| | $ClO_3{}^- + 3H_2O + 6\bar{e} \leftrightarrows Cl^- + 6OH^-$ | 0.63 |
| | $ClO^- + H_2O + 2\bar{e} \leftrightarrows Cl^- + 2OH^-$ | 0.89 |
| | $Cl_2 + 2\bar{e} \leftrightarrows 2Cl^-$ | 1.36 |
| Chromium | $Cr^{3+} + \bar{e} \leftrightarrows Cr^{2+}$ | −0.424 |
| | $CrO_4{}^{2-} + 4H_2O + 3\bar{e} \leftrightarrows [Cr(OH)_6]^{3-} + 2OH^-$ | −0.72 |
| | $Cr_2O_7{}^{2-} + 14H^+ + 6\bar{e} \leftrightarrows 2Cr^{3+} + 7H_2O$ | 1.38 |
| Cobalt | $Co(OH)_3 + \bar{e} \leftrightarrows Co(OH)_2 + OH^-$ | 0.42 |
| Fluorine | $F_2 + 2\bar{e} \leftrightarrows 2F^-$ | 2.87 |
| Gold | $Au^{3+} + 3\bar{e} \leftrightarrows Au$ | 1.498 |
| Hydrogen | $2H^+ + 2\bar{e} \leftrightarrows H_2$ | 0.00 |
| Iodine | $I_2 + 2\bar{e} \leftrightarrows 2I^-$ | 0.536 |
| | $I_3{}^- + 2\bar{e} \leftrightarrows 3I^-$ | 0.545 |
| | $2IO_3{}^- + 12H^+ + 10\bar{e} \leftrightarrows I_2 + 6H_2O$ | 1.19 |
| Iron | $Fe(OH)_3 + \bar{e} \leftrightarrows Fe(OH)_2 + OH^-$ | −0.53 |
| | $Fe^{2+} + 2\bar{e} \leftrightarrows Fe$ | −0.440 |
| | $Fe^{3+} + 3\bar{e} \leftrightarrows Fe$ | −0.037 |
| | $[Fe(CN)_6]^{3-} + \bar{e} \leftrightarrows [Fe(CN)_6]^{4-}$ | 0.361 |
| | $Fe^{3+} + \bar{e} \leftrightarrows Fe^{2+}$ | 0.771 |
| | $FeO_4{}^{2-} + 8H^+ + 3\bar{e} \leftrightarrows Fe^{3+} + 4H_2O$ | 1.7 |
| Lead | $PbO_2 + 4H^+ + 2\bar{e} \leftrightarrows Pb^{2+} + 2H_2O$ | 1.44 |

| | | |
|---|---|---|
| **Manganese** | $MnO_4^- + \bar{e} \leftrightarrows MnO_4^{2-}$ | 0.564 |
| | $MnO_4^- + 2H_2O + 3\bar{e} \leftrightarrows MnO_2 + 4OH^-$ | 0.60 |
| | $MnO_4^- + 8H^+ + 5\bar{e} \leftrightarrows Mn^{2+} + 4H_2O$ | 1.51 |
| **Mercury** | $Hg^{2+} + 2\bar{e} \leftrightarrows Hg$ | 0.854 |
| **Nickel** | $Ni(OH)_3 + \bar{e} \leftrightarrows Ni(OH)_2 + OH^-$ | 0.52 |
| **Nitrogen** | $NO_2^- + H_2O + \bar{e} \leftrightarrows NO + 2OH^-$ | −0.46 |
| | $NO_3^- + H_2O + 2\bar{e} \leftrightarrows NO_2^- + 2OH^-$ | 0.01 |
| | $NO_3^- + 2H^+ + \bar{e} \leftrightarrows NO_2 + H_2O$ | 0.8 |
| | $NO_3^- + 3H^+ + 2\bar{e} \leftrightarrows HNO_2 + H_2O$ | 0.94 |
| | $HNO_2 + H^+ + \bar{e} \leftrightarrows NO + H_2O$ | 0.99 |
| **Oxygen** | $O_2 + 2H_2O + 4\bar{e} \leftrightarrows 4OH^-$ | 0.401 |
| | $O_2 + 2H^+ + 2\bar{e} \leftrightarrows H_2O_2$ | 0.695 |
| | $O_2 + 4H^+ + 4\bar{e} \leftrightarrows 2H_2O$ | 1.228 |
| | $H_2O_2 + 2H^+ + 2\bar{e} \leftrightarrows 2H_2O$ | 1.763 |
| | $O_3 + 2H^+ + 2\bar{e} \leftrightarrows O_2 + H_2O$ | 2.07 |
| **Phosphorus** | $PO_4^{3-} + 2H_2O + 2\bar{e} \leftrightarrows PO_3H^{2-} + 3OH^-$ | −1.12 |
| | $H_3PO_4 + 4H^+ + 4\bar{e} \leftrightarrows HPO_2H_2 + 2H_2O$ | −0.39 |
| | $H_3PO_4 + 2H^+ + 2\bar{e} \leftrightarrows H_2PO_3H + H_2O$ | −0.276 |
| **Selenium** | $H_2SeO_3 + 4H^+ + 4\bar{e} \leftrightarrows Se + 3H_2O$ | 0.741 |
| | $Se + 2H^+ + 2\bar{e} \leftrightarrows H_2Se$ | −0.011 |
| | $SeO_4^{2-} + 4H^+ + 2\bar{e} \leftrightarrows H_2SeO_3 + H_2O$ | 1.15 |
| **Sulphur** | $SO_4^{2-} + H_2O + 2\bar{e} \leftrightarrows SO_3^{2-} + 2OH^-$ | −0.936 |
| | $S + 2\bar{e} \leftrightarrows S^{2-}$ | −0.476 |
| | $SO_4^{2-} + 8H^+ + 8\bar{e} \leftrightarrows S^{2-} + 4H_2O$ | 0.149 |
| | $SO_4^{2-} + 2H^+ + 2\bar{e} \leftrightarrows SO_3^{2-} + H_2O$ | 0.158 |
| | $SO_4^{2-} + 8H^+ + 6\bar{e} \leftrightarrows S + 4H_2O$ | 0.357 |
| | $S_2O_8^{2-} + 2\bar{e} \leftrightarrows 2SO_4^{2-}$ | 1.96 |
| **Silver** | $Ag^+ + \bar{e} \leftrightarrows Ag$ | 0.799 |
| **Tin** | $[Sn(OH)_6]^{2-} + 2\bar{e} \leftrightarrows [Sn(OH)_4]^{2-} + 2OH^-$ | −0.93 |
| | $Sn^{4+} + 2\bar{e} \leftrightarrows Sn^{2+}$ | 0.151 |
| **Zinc** | $[Zn(OH)_4]^{2-} + 2\bar{e} \leftrightarrows Zn + 4OH^-$ | −1.199 |
| | $Zn^{2+} + 2\bar{e} \leftrightarrows Zn$ | −0.763 |

*Table 11*

**Instability constants of certain coordination ions in aqueous solutions at 25 ºC**

| Equation for complex ion dissociation | Instability constants | Equation for complex ion dissociation | Instability constants |
|---|---|---|---|
| $[Ag(CN)_2]^- \leftrightarrows Ag^+ + 2CN^-$ | $1.1 \times 10^{-21}$ | $[Fe(CN)_6]^{3-} \leftrightarrows Fe^{3+} + 6CN^-$ | $1.3 \times 10^{-44}$ |
| $[Ag(NH_3)_2]^+ \leftrightarrows Ag^+ + 2NH_3$ | $9.3 \times 10^{-8}$ | $[Fe(CN)_6]^{4-} \leftrightarrows Fe^{2+} + 6CN^-$ | $1.3 \times 10^{-37}$ |
| $[Ag(NO_2)_2]^- \leftrightarrows Ag^+ + 2NO_2^-$ | $1.8 \times 10^{-3}$ | $[Fe(NH_3)_4]^{2+} \leftrightarrows Fe^{2+} + 4NH_3$ | $2.0 \times 10^{-4}$ |
| $[Ag(S_2O_3)_2]^{3-} \leftrightarrows Ag^+ + 2S_2O_3^{2-}$ | $1.1 \times 10^{-13}$ | $[Fe(OH)_4]^{2-} \leftrightarrows Fe^{2+} + 4OH^-$ | $2.7 \times 10^{-9}$ |
| $[Al(OH)_6]^{3-} \leftrightarrows Al^{3+} + 6OH^-$ | $1.0 \times 10^{-33}$ | $[FeF_6]^{3-} \leftrightarrows Fe^{3+} + 6F^-$ | $7.94 \times 10^{-17}$ |
| $[Au(CN)_2]^- \leftrightarrows Au^+ + 2CN^-$ | $5.0 \times 10^{-39}$ | $[Hg(CN)_4]^{2-} \leftrightarrows Hg^{2+} + 4CN^-$ | $4.0 \times 10^{-42}$ |
| $[AuCl_4]^- \leftrightarrows Au^{3+} + 4Cl^-$ | $5.0 \times 10^{-22}$ | $[HgBr_4]^{2-} \leftrightarrows Hg^{2+} + 4Br^-$ | $1.0 \times 10^{-21}$ |
| $[Cd(CN)_4]^{2-} \leftrightarrows Cd^{2+} + 4CN^-$ | $7.8 \times 10^{-18}$ | $[HgCl_4]^{2-} \leftrightarrows Hg^{2+} + 4Cl^-$ | $8.5 \times 10^{-16}$ |
| $[Cd(NH_3)_4]^{2+} \leftrightarrows Cd^{2+} + 4NH_3$ | $7.6 \times 10^{-8}$ | $[HgI_4]^{2-} \leftrightarrows Hg^{2+} + 4I^-$ | $1.5 \times 10^{-30}$ |
| $[Cd(OH)_4]^{2-} \leftrightarrows Cd^{2+} + 4OH^-$ | $3.8 \times 10^{-9}$ | $[Ni(NH_3)_6]^{2+} \leftrightarrows Ni^{2+} + 6NH_3$ | $1.9 \times 10^{-9}$ |
| $[Co(NH_3)_6]^{2+} \leftrightarrows Co^{2+} + 6NH_3$ | $4.1 \times 10^{-5}$ | $[Sn(OH)_4]^{2-} \leftrightarrows Sn^{2+} + 4OH^-$ | $4.0 \times 10^{-26}$ |
| $[Co(NH_3)_6]^{3+} \leftrightarrows Co^{3+} + 6NH_3$ | $6.2 \times 10^{-36}$ | $[Sn(OH)_6]^{2-} \leftrightarrows Sn^{4+} + 6OH^-$ | $1.0 \times 10^{-63}$ |
| $[Cu(NH_3)_4]^{2+} \leftrightarrows Cu^{2+} + 4NH_3$ | $2.1 \times 10^{-13}$ | $[Zn(OH)_4]^{2-} \leftrightarrows Zn^{2+} + 4OH^-$ | $2.0 \times 10^{-18}$ |

*Table 12*

**Identification of certain inorganic compounds, cations and anions**

| Cation, anion, compound | Conditions of chemical reactions | Analytical effect |
|---|---|---|
| Lithium $Li^+$ | A. Effect of carbonate solution on heating:<br>$$2LiCl + Na_2CO_3 = Li_2CO_3(s) + 2NaCl$$<br>$$2Li^+ + CO_3^{2-} = Li_2CO_3(s)$$<br>B. Effect of phosphate solution:<br>$$3LiCl + Na_3PO_4 = Li_3PO_4(s) + 3NaCl$$<br>$$3Li^+ + PO_4^{3-} = Li_3PO_4(s)$$<br>C. Adding salts to the colorless flame of the burner | A. *After cooling the solution, a white crystalline precipitate is formed.*<br><br>B. *A white crystalline precipitate is formed.*<br><br>C. *The color of the flame is red.* |
| Sodium $Na^+$ | A. Effect of potassium pyroantimonate solution on boiling:<br>$$NaCl + K[Sb(OH)_6] = Na[Sb(OH)_6](s) + KCl$$<br>$$Na^+ + [Sb(OH)_6]^- = Na[Sb(OH)_6](s)$$<br>B. Adding salts to the colorless flame of the burner | A *After cooling the solution, a thick white precipitate is formed.*<br><br>B. *The yellow flame color.* |
| Potassium $K^+$ | A. The action of a freshly made acidified solution of sodium hexanitritocobaltate(III):<br>$$K_2SO_4 + Na_3[Co(NO_2)_6]^{3-} = K_2Na[Co(NO_2)_6] (s) + Na_2SO_4$$<br>$$2K^+ + Na^+ + [Co(NO_2)_6]^{3-} = K_2Na[Co(NO_2)_6](s)$$<br>B. Adding salts to the colorless flame of the burner | A. *Immediately a yellow or orange-yellow precipitate is formed.*<br><br>B. *Purple flame color.* |
| Copper(II) $Cu^{2+}$ | A. Addition of ammonia solution to solutions of copper (II) salts:<br>$$2CuSO_4 + 2NH_3 \cdot H_2O = (CuOH)_2SO_4(s) + (NH_4)_2SO_4,$$<br>$$2Cu^{2+} + SO_4^{2-} + 2NH_3 \cdot H_2O = (CuOH)_2SO_4(s) + 2NH_4^+,$$<br>$$(CuOH)_2SO_4 + 8NH_3 \cdot H_2O = [Cu(NH_3)_4]SO_4 + [Cu(NH_3)_4](OH)_2 + 8H_2O$$<br>$$(CuOH)_2SO_4 + 8NH_3 \cdot H_2O = 2[Cu(NH_3)_4]^{2+} + SO_4^{2-} + 2OH^- + 8H_2O$$<br>B. Action of alkali solution, followed by heating:<br>$$CuSO_4 + 2NaOH = Cu(OH)_2(s) + Na_2SO_4,$$<br>$$Cu^{2+} + 2OH^- = Cu(OH)_2(s),$$<br>$$Cu(OH)_2(s) = CuO + H_2O$$ | A. *A blue precipitate is formed, which dissolves in excess ammonia to form a solution of intensely blue color.*<br><br>B. *A blue precipitate, which is insoluble in excess of alkali, is formed, which turns black when heated.* |
| Silver $Ag^+$ | A. Diluted $HNO_3$ and sodium chloride solution were added to the solution of the silver salt:<br>$$AgNO_3 + NaCl = AgCl(s) + NaNO_3$$<br>$$Ag^+ + Cl^- = AgCl(s)$$<br>$$AgCl(s) + 2NH_4OH = [Ag(NH_3)_2]Cl + 2H_2O$$<br>B. The action of alkali solutions:<br>$$2AgNO_3 + 2NaOH = Ag_2O(s) + 2NaNO_3 + H_2O$$<br>$$2Ag^+ + 2OH^- = Ag_2O(s) + H_2O$$ | A. *A white caseous precipitate is formed, insoluble in dilute $HNO_3$ and soluble in ammonia solution.*<br><br>B. *A black precipitate is formed, soluble in ammonia solution.* |

| Cation, anion, compound | Conditions of chemical reactions | Analytical effect |
|---|---|---|
| Magnesium $Mg^{2+}$ | A. The action alkali solution to magnesium salt:<br><br>$$MgSO_4 + 2NaOH = Mg(OH)_2(s) + Na_2SO_4$$<br>$$Mg^{2+} + 2OH^- = Mg(OH)_2(s)$$<br><br>B. To a solution of magnesium salt was added a solution of $NH_4Cl$, solutions of ammonia and $Na_2HPO_4$:<br><br>$$MgSO_4 + Na_2HPO_4 + NH_4OH = MgNH_4PO_4(s) + Na_2SO_4 + H_2O$$<br>$$Mg^{2+} + HPO_4^{2-} + NH_4OH = MgNH_4PO_4(s) + H_2O$$ | A. *White amorphous precipitate is formed.*<br><br><br><br>B. *A white crystalline precipitate is formed, soluble in dilute mineral and acetic acids.* |
| Calcium $Ca^{2+}$ | A. To a solution of calcium salts add a solution of ammonium oxalate:<br>$$CaCl_2 + (NH_4)C_2O_4 = CaC_2O_4(s) + 2NH_4Cl$$<br>$$Ca^{2+} + C_2O_4^{2-} = CaC_2O_4(s)$$<br>B. Adding salts to the colorless flame of the burner | A. *white precipitate is formed, insoluble in ammonia solution, soluble in dilute mineral acids.*<br>B. *Brick-red flame color.* |
| Strontium $Sr^{2+}$ | A. To the solution of strontium salt is added a solution of sulphate:<br>$$SrCl_2 + K_2SO_4 = SrSO_4(s) + 2KCl$$<br>$$Sr^{2+} + SO_4^{2-} = SrSO_4(s)$$<br>B. Adding salts to the colorless flame of the burner | A. *A white precipitate is formed.*<br><br><br><br>B. *Carmine-red flame color.* |
| Barium $Ba^{2+}$ | A. To a solution of barium salt is added a solution of sodium sulphate:<br>$$BaCl_2 + Na_2SO_4 = BaSO_4(s) + 2NaCl$$<br>$$Ba^{2+} + SO_4^{2-} = BaSO_4(s)$$<br>B. To a solution of barium salt is added a solution of chromate (dichromate):<br>$$2BaCl_2 + K_2Cr_2O_7 + H_2O = 2BaCrO_4(s) + 2HCl + 2KCl$$<br>$$2Ba^{2+} + Cr_2O_7^{2-} + H_2O = 2BaCrO_4(s) + 2H^+$$<br>C. Adding salts to the colorless flame of the burner | A. *A white crystalline precipitate is formed, insoluble in dilute mineral acids.*<br><br>B *A yellow precipitate is formed.*<br><br><br><br>C. *Yellow-green flame color.* |
| Zinc $Zn^{2+}$ | To a neutral solution of zinc salt is added a solution of sodium sulphide:<br>$$ZnSO_4 + Na_2S = ZnS(s) + Na_2SO_4$$<br>$$Zn^{2+} + S^{2-} = ZnS(s)$$ | *A white precipitate is formed, soluble in dilute hydrochloric acid.* |
| Mercury $Hg^{2+}$ | Effect of potassium iodide solution on solution of mercury (II) salt:<br>$$Hg(NO_3)_2 + 2KI = HgI_2(s) + 2KNO_3$$<br>$$Hg^{2+} + 2I^- = HgI_2(s)$$<br>$$HgI_2(s) + 2KI = K_2[HgI_4]$$<br>$$HgI_2(s) + 2I^- = [HgI_4]^{2-}$$ | *An orange precipitate is formed, which dissolves in excess of reagent to form a colorless solution.* |

| Cation, anion, compound | Conditions of chemical reactions | Analytical effect |
|---|---|---|
| Borate (meta-, tetra-) $BO_2^-$, $B_4O_7^{2-}$ | Heating of dry salts in the presence of concentrated $H_2SO_4$ with methanol (ethanol) - trimethyl (ethyl) orthoborates are formed:<br>$$Na_2B_4O_7 + H_2SO_4 + 5H_2O = Na_2SO_4 + 4H_3BO_3\downarrow$$<br>$$B_4O_7^{2-} + 2H^+ + 5H_2O = 4H_3BO_3(s)$$<br>$$H_3BO_3(s) + 3CH_3OH = B(OCH_3)_3(g) + 3H_2O$$<br>$$2B(OCH_3)_3 + 18O_2 = B_2O_3 + 6CO_2 + 9H_2O$$ | *The created product burns with a green flame.* |
| Aluminium $Al^{3+}$ | Effect on aluminum salts of ammonia solution:<br>$$AlCl_3 + 3NH_4OH = Al(OH)_3(s) + 3NH_4Cl$$<br>$$Al^{3+} + 3NH_4OH = Al(OH)_3(s) + 3NH_4^+$$<br>$$Al(OH)_3(s) + 3HCl = AlCl_3 + 3H_2O$$<br>$$Al(OH)_3(s) + 3H^+ = Al^{3+} + 3H_2O$$<br>$$Al(OH)_3(s) + 3NaOH = Na_3[Al(OH)_6];$$<br>$$Al(OH)_3(s) + 3OH^- = [Al(OH)_6]^{3-}$$ | *A colorless gelatinous precipitate is formed, soluble in mineral acids and alkalis.* |
| Carbon (II) oxide $CO$ | Gas passing through a solution of palladium (II) chloride:<br>$$CO + PdCl_2 + H_2O = Pd(s) + 2HCl + CO_2$$ | *Darkening of the solution.* |
| Carbonate (hydrogen-carbonate) $CO_3^{2-}$ ($HCO_3^-$) | A. To the dry carbonate (hydrogen carbonate) or to its solution add dilute hydrochloric acid:<br>$$Na_2CO_3 + 2HCl = 2NaCl + H_2O + CO_2(g)$$<br>$$CO_3^{2-} + 2H^+ = H_2O + CO_2(g)$$<br>$$Ca(OH)_2 + CO_2(g) = CaCO_3(s) + H_2O$$<br>$$CaCO_3(s) + CO_2(g) + H_2O = Ca(HCO_3)_2$$<br>B. Add a solution of phenolphthalein to the carbonate solution | *A. A gas is released, which forms a white precipitate when passing through limewater. With excess gas, the precipitate dissolves.*<br><br><br><br>*B. The solution turns crimson (unlike hydrogen carbonates).* |
| Silicate $SiO_3^{2-}$ | Dilute hydrochloric or sulphuric acid is added to the silicate solution:<br>$$Na_2SiO_3 + 2HCl = 2NaCl + H_2SiO_3(s)$$<br>$$SiO_3^{2-} + 2H^+ = H_2SiO_3(s)$$ | *A colorless gelatinous precipitate is formed.* |
| Acetate $CH_3COO^-$ | The effect of sulphuric acid on dry salts or their solutions:<br>$$2CH_3COONa + H_2SO_4 = CH_3COOH + Na_2SO_4$$<br>$$CH_3COO^- + H^+ = CH_3COOH$$ | *The characteristic smell of acetic acid.* |
| Tin $Sn^{2+}$ | Action on the tin salt of the ammonia solution:<br>$$SnCl_2 + 2NH_4OH = Sn(OH)_2(s) + 2NH_4Cl$$<br>$$Sn^{2+} + 2NH_4OH = Sn(OH)_2(s) + 2NH_4^+$$<br>$$Sn(OH)_2(s) + 2HCl = SnCl_2 + 2H_2O$$<br>$$Sn(OH)_2(s) + 2H^+ = Sn^{2+} + 2H_2O$$<br>$$Sn(OH)_2(s) + 2NaOH = Na_2[Sn(OH)_4]$$<br>$$Sn(OH)_2(s) + 2OH^- = [Sn(OH)_4]^{2-}$$ | *A white precipitate is formed, soluble in mineral acids and alkalis.* |

| Cation, anion, compound | Conditions of chemical reactions | Analytical effect |
|---|---|---|
| Lead $Pb^{2+}$ | Effect of potassium iodide solution on the lead salts: $$Pb(NO_3)_2 + 2KI = PbI_2(s) + 2KNO_3$$ $$Pb^{2+} + 2I^- = PbI_2(s)$$ $$PbI_2(s) + 2KI = K_2[PbI_4]$$ $$PbI_2(s) + 2I^- = [PbI_4]^{2-}$$ | *A yellow precipitate is formed, which dissolves when boiling the solution or in excess of the reagent.* |
| Ammonium $NH_4^+$ | A. The solution of ammonium salt is heated with a solution of sodium hydroxide: $$NH_4Cl + NaOH = NH_3(g) + NaCl + H_2O$$ $$NH_4^+ + OH^- = NH_3(g) + H_2O$$ $$2NH_3(g) + Hg_2Cl_2 = HgNH_2Cl + Hg(s) + NH_4Cl$$ B. The action of an alkaline solution of potassium tetraiodomercurate (II) (Nessler's reagent): $$NH_4^+ + 2[HgI_4]^{2-} + 2OH^- = [Hg_2N\ H_2O]I(s) + 7I^- + 2H_2O$$ | *A. Gas with a characteristic odor is formed , which causes the blue of wet red litmus paper and the blackening of the paper moistened with a solution of mercury(I) salt .* *B. A brown (rusty) precipitate is formed.* |
| Nitrate $NO_3^-$ | A. To the solution add conc. sulphuric acid, a piece of metallic copper and heated $$Cu + 2NaNO_3 + 2H_2SO_{4:} = CuSO_4 + 2NO_2(g)+ 2H_2O + Na_2SO_4$$ $$Cu + 2NO_3^- + 4H^+ = Cu^{2+} + 2NO_2(g) + 2H_2O$$ B. Nitrates do not discolour potassium permanganate solution, acidified with dilute sulfuric acid (unlike nitrite) | *Brown gas is released.* |
| Nitrite $NO_2^-$ | To the solution was added dilute sulphuric acid: $$2NaNO_2 + H_2SO_4 = NO_2(g) + NO + Na_2SO_4 + H_2O$$ $$2NO_2^- + 2H^+ = NO_2(g) + NO + H_2O$$ | *Brown gas (unlike nitrates) is released.* |
| Phosphate $PO_4^{3-}$ | A. To a neutral solution of phosphate is added a few drops of a solution of silver nitrate: $$Na_3PO_4 + 3AgNO_3 + = Ag_3PO_4(s) + 3NaNO_3$$ $$PO_4^{3-} + 3Ag^+ = Ag_3PO_4(s)$$ B. To the solution of phosphate is added a solution of NH$_4$Cl, solutions of ammonia and magnesium sulphate: $$Na_2HPO_4 + MgSO_4 + NH_4OH = MgNH_4PO_4(s)+ Na_2SO_4 + H_2O$$ $$HPO_4^{2-} + Mg^{2+} + NH_4OH = MgNH_4PO_4(s) + H_2O$$ | *A. A yellow precipitate is formed, soluble in dilute nitric acid and ammonia solution.* *B. A white crystalline precipitate is formed, soluble in dilute mineral and acetic acids.* |
| Arsenic compounds | Effect on metallic zinc on arsenic compounds in hydrochloric acid: $$As_2O_3 + 6Zn + 12HCl = 2AsH_3(g) + 6ZnCl_2 + 3H_2O$$ $$2AsH_3(g) = 2As(s) + 3H_2$$ | *The gas is released, which decomposes when heated, forming a coating with a metallic luster. (March test).* |

| Cation, anion, compound | Conditions of chemical reactions | Analytical effect |
|---|---|---|
| Bismuth $Bi^{3+}$ | A. To a solution of bismuth salt is added a solution of sodium sulphide:<br>$$2Bi(NO_3)_3 + 3Na_2S = Bi_2S_3(s) + 6NaNO_3$$<br>$$2Bi^{3+} + 3S^{2-} = Bi_2S_3(s)$$<br>B. A potassium iodide solution is added to the bismuth salt solution:<br>$$Bi(NO_3)_3 + 3KI = BiI_3(s) + 3KNO_3$$<br>$$Bi^{3+} + 3I^- = BiI_3(s)$$<br>$$BiI_3(s) + KI = K[BiI_4]$$<br>$$BiI_3(s) + I^- = [BiI_4]^-$$ | A. *A brown-black precipitate is formed, soluble in concentrated nitric acid.*<br><br>B. *A black precipitate is formed, soluble in excess of the reagent with the formation of a yellow-orange solution.* |
| Ozon $O_3$ | A. Ozone is passed through a solution of potassium iodide:<br>$$2KI + O_3 + H_2O = I_2 + 2KOH + O_2$$<br>$$2I^- + O_3 + H_2O = I_2 + 2OH^- + O_2$$<br>B. Effect on wet iodine starch paper | A. *The solution becomes brown in color.*<br><br><br>B. *The paper turns blue.* |
| Hydrogen peroxide $H_2O_2$ | To a solution of $H_2O_2$ add diethyl ether, potassium dichromate solution and $H_2SO_4$(conc):<br>$$4H_2O_2 + K_2Cr_2O_7 + H_2SO_4 = 2CrO_5 + K_2SO_4 + 5H_2O$$<br>$$4H_2O_2 + Cr_2O_7^{2-} + 2H^+ = 2CrO_5 + 5H_2O$$ | *The ether layer is colored blue.* |
| Sulphide $S^{2-}$ | Effect on soluble sulphides of solution of plumbum (II) acetate (or nitrate):<br>$$Na_2S + Pb(NO_3)_2 = PbS(s) + 2NaNO_3$$<br>$$S^{2-} + Pb^{2+} = PbS(s)$$ | *A black precipitate is formed.* |
| Sulphate $SO_4^{2-}$ | To a solution of sulphate is added a solution of barium chloride:<br>$$Na_2SO_4 + BaCl_2 = BaSO_4(s) + 2NaCl$$<br>$$SO_4^{2-} + Ba^{2+} = BaSO_4(s)$$ | *A white precipitate is formed, insoluble in dilute mineral acids.* |
| Sulphite $SO_3^{2-}$ | A. To the solution of sulphite is added dilute hydrochloric acid:<br>$$Na_2SO_3 + 2HCl = SO_2(g) + 2NaCl + H_2O$$<br>$$SO_3^{2-} + 2H^+ = SO_2(g) + H_2O$$<br>B. To the solution of sulphite was added a solution of barium chloride:<br>$$Na_2SO_3 + BaCl_2 = BaSO_3(s) + 2NaCl$$<br>$$SO_3^{2-} + Ba^{2+} = BaSO_3(s)$$<br>C. A few drops of iodine solution are added to the sulphite solution:<br>$$Na_2SO_3 + I_2 + H_2O = 2HI + Na_2SO_4$$ | A. *The gas with a characteristic sharp odor is gradually released.*<br><br>B. *A white precipitate is formed, soluble in dilute hydrochloric acid (unlike sulphates).*<br><br>C. *The iodine solution is discolored.* |
| Thiosulphate $S_2O_3^{2-}$ | A. The effect of dilute $H_2SO_4$ or HCl on the thiosulphate solution:<br>$$Na_2S_2O_3 + 2HCl = SO_2(g) + S(s) + 2NaCl + H_2O$$<br>$$S_2O_3^{2-} + 2H^+ = SO_2(g) + S(s) + H_2O$$ | A. *Yellow opalescence of the solution is formed and a characteristic smell of burnt matches is felt*<br>B *The iodine solution is discolored.* |

| Cation, anion, compound | Conditions of chemical reactions | Analytical effect |
|---|---|---|
| | B. Effect of iodine solution on thiosulphates: $$2Na_2S_2O_3 + I_2 = Na_2S_4O_6 + 2NaI$$ $$2S_2O_3^{2-} + I_2 = S_4O_6^{2-} + 2I^-$$ | |
| Chromium $Cr^{3+}$ | A. To the solution of $Cr^{3+}$ salt add an excess of alkali solution, and $H_2O_2$ when heated: $$CrCl_3 + 3NaOH = Cr(OH)_3(s) + 3NaCl$$ $$Cr^{3+} + 3OH^- = Cr(OH)_3(s)$$ $$Cr(OH)_3(s) + 3NaOH = Na_3[Cr(OH)_6]$$ $$Cr(OH)_3(s) + 3OH^- = [Cr(OH)_6]^{3-}$$ $$2Na_3[Cr(OH)_6] + 3H_2O_2 = 2Na_2CrO_4 + 2NaOH + 8H_2O$$ B. Effect on chromium salt of ammonia solution: $$CrCl_3 + 3NH_4OH = Cr(OH)_3(s) + 3NH_4Cl$$ $$Cr^{3+} + 3NH_4OH = Cr(OH)_3(s) + 3NH_4^+$$ $$Cr(OH)_3(s) + 3HCl = CrCl_3 + 3H_2O$$ $$Cr(OH)_3(s) + 3H^+ = Cr^{3+} + 3H_2O$$ $$Cr(OH)_3(s) + 3NaOH = Na_3[Cr(OH)_6];$$ $$Cr(OH)_3(s) + 3OH^- = [Cr(OH)_6]^{3-}$$ | A. *The formed gray-green precipitate dissolves to form a green solution, which turns yellow.* <br><br><br><br><br> B *Gray-green precipitate is formed, soluble in mineral acids and alkalis.* |
| Chromate (dichromate) $CrO_4^{2-}$ $(Cr_2O_7^{2-})$ | A. To the solution of chromate (dichromate) is added a solution of barium or lead salt: $$K_2Cr_2O_7 + 2BaCl_2 + H_2O = 2BaCrO_4(s) + 2HCl + 2KCl$$ $$Cr_2O_7^{2-} + 2Ba^{2+} + H_2O = 2BaCrO_4(s) + 2H^+$$ $$K_2CrO_4 + Pb(NO_3)_2 = PbCrO_4(s) + 2KNO_3$$ $$CrO_4^{2-} + Pb^{2+} = PbCrO_4(s)$$ B. To a solution of dichromate add diethyl ether, $H_2SO_{4(conc)}$ and $H_2O_2$: $$K_2Cr_2O_7 + 4H_2O_2 + H_2SO_4 = 2CrO_5 + K_2SO_4 + 5H_2O$$ $$4H_2O_2 + Cr_2O_7^{2-} + 2H^+ = 2CrO_5 + 5H_2O$$ | A. *A yellow precipitate is formed.* <br><br><br><br><br> B. *The ether layer is colored blue.* |
| Fluoride $F^-$ | Effect of soluble calcium salts on fluoride solutions: $$CaCl_2 + 2NaF = CaF_2(s) + 2NaCl$$ $$Ca^{2+} + 2F^- = CaF_2(s)$$ | A *white precipitate is formed.* |
| Chloride $Cl^-$ | To the chloride solution add dilute $HNO_3$ and a solution of silver nitrate: $$NaCl + AgNO_3 = AgCl(s) + NaNO_3$$ $$Cl^- + Ag^+ = AgCl(s)$$ $$AgCl(s) + 2NH_4OH = [Ag(NH_3)_2]Cl + 2H_2O$$ | A *white caseous precipitate is formed, insoluble in dilute nitric acid and soluble in ammonia solution.* |

| Cation, anion, compound | Conditions of chemical reactions | Analytical effect |
|---|---|---|
| Bromide $Br^-$ | To the bromide solution add dilute $HNO_3$ and a solution of silver nitrate:<br>$NaBr + AgNO_3 = AgBr(s) + NaNO_3$<br>$Br^- + Ag^+ = AgBr(s)$<br>$AgBr(s) + 2NH_4OH = [Ag(NH_3)_2]Br + 2H_2O$ | *A yellowish caseous precipitate is formed, insoluble in dilute nitric acid and hardly soluble in ammonia solution.* |
| Iodine $I_2$ | Starch paste | *Blue color.* |
| Iodide $I^-$ | A. To the solution of iodide is added dilute $H_2SO_4$, sodium nitrite solution or solution of iron (III) chloride and 2 mL of chloroform:<br>$2NaNO_2 + 2KI + 2H_2SO_4 = I_2 + 2NO + K_2SO_4 + Na_2SO_4 + 2H_2O$<br>$2KI + 2FeCl_3 = I_2 + 2FeCl_2 + 2KCl$<br>B. To the solution of iodide add dilute $HNO_3$ and a solution of silver nitrate:<br>$KI + AgNO_3 = AgI(s) + KNO_3$<br>$I^- + Ag^+ = AgI(s)$<br>C. Heating of iodides with concentrated sulphuric acid:<br>$8HI + H_2SO_4 = 4I_2(g) + H_2S + 4H_2O$ | *A. The chloroform layer is colored in purple.*<br><br>*B The yellow caseous precipitate is formed, insoluble in dilute nitric acid and ammonia solution.*<br>*C Purple iodine is released.* |
| Manganese (II) $Mn^{2+}$ | A. To the solution of manganese salts is added a solution of sodium sulphide:<br>$Mn(NO_3)_2 + Na_2S = MnS(s) + 2NaNO_3$<br>$Mn^{2+} + S^{2-} = MnS(s)$<br>B. Adding of lead (IV) oxide in acidic medium:<br>$3MnSO_4 + 5PbO_2 + 6HNO_3 = 2HMnO_4 + 3Pb(NO_3)_2 + 2PbSO_4 + 2H_2O$ | *A Pink precipitate is formed, soluble in mineral and acetic acids.*<br><br>*B The solution is reddish-purple.* |
| Iron (II) $Fe^{2+}$ | A. Diluted HCl and solution of potassium hexacyanoferrate(III) were added to the solution of iron (II) salt:<br>$FeSO_4 + K_3[Fe(CN)_6] = KFe[Fe(CN)_6](s) + K_2SO_4$<br>$Fe^{2+} + K^+ + [Fe(CN)_6]^{3-} = KFe[Fe(CN)_6](s)$<br>B. A solution of ammonium sulphide is added to the solution of the iron(II) salt:<br>$FeSO_4 + (NH_4)_2S = FeS(s) + (NH_4)_2SO_4$<br>$Fe^{2+} + S^{2-} = FeS(s)$ | *A Blue precipitate is formed.*<br><br>*B Black precipitate is formed, soluble in dilute mineral acids.* |
| Iron (III) $Fe^{3+}$ | A. Diluted HCl and solution of potassium hexacyanoferrate (II) were added to the solution of iron (III) salt:<br>$FeCl_3 + K_4[Fe(CN)_6] = KFe[Fe(CN)_6](s) + 3KCl$<br>$Fe^{3+} + K^+ + [Fe(CN)_6]^{4-} = KFe[Fe(CN)_6](s)$<br>B. Dilute hydrochloric acid and $NH_4SCN$ solution are added to the solution of iron(III) salt:<br>$FeCl_3 + 3NH_4SCN = Fe(SCN)_3 + 3NH_4Cl$<br>$Fe^{3+} + 3 SCN^- = Fe(SCN)_3$ | *A Blue precipitate is formed.*<br><br>*B Red color appears.* |

# CONTENTS

**Навчальне видання**

**ЛЕВІТІН** Євген Якович
**ВЕДЕРНИКОВА** Ірина Олексіївна
**КЛИМЕНКО** Ліна Юріївна
**КРИСЬКІВ** Олег Степанович

# ЗАГАЛЬНА ТА НЕОРГАНІЧНА ХІМІЯ ЛАБОРАТОРНИЙ ПРАКТИКУМ

**Англійською мовою**