Subject 10. Formation of complexes in heterogeneous systems

1. Importance

Coordination compounds have specific structure and bond type. A great many compounds in nature are classified as coordination compounds because of their structure, properties and biological activity. Metal-containing enzymes, hemoglobin, myoglobin, vitamin B_{12} are biologically active coordination compounds.

A specific group of compounds, that are able to form complexes with many cations, is widely used to dissolve stones in the kidneys and the gall bladder. They are used as stabilizers in blood conservation, because they bind the metal ions, which catalyze oxidation reactions. They are also used to remove ions of toxic metals and radioactive isotopes from the organism.

Competences

Capacity for abstract thinking, analysis and synthesis, capacity to learn.

Ability to apply knowledge in practical situations.

Ability to assess and ensure quality of work.

Ability to communicate in English language both orally and in writing.

Use English language in professional and business communications and preparation of documents.

Ability to choose strategy of communication; ability to work in a team; skills of interpersonal interaction.

Ability to exercise self-control and healthy lifestyle, adaptability and ability to perform in new situations.

Motivation and perseverance in achieving goals.

Skills in using information and communication technologies.

Desire to preserve the environment.

Ability to evaluate results of laboratory and practical studies.

Ability to solve typical problems and practical problems in learning.

2. Concrete aims

Know principles of structure of coordination compounds.

Interpret properties of structure of coordination compounds as the basis for their use in chelatotherapy.

3. Basic knowledge, skills necessary for studying the subject (interdisciplinary integration)

Previous subjects	Obtained skills

1. Foreign language for professional purposes	Possess basic knowledge of English language. Be able to communicate in English language. Use English language in professional activity.
2. Latin language and medical therminology	Master medical therminology in Latin language.
3. Safety, basics of bioethics and biosafety	Be able to exercise self-control, healthy lifestyle, be able to adapt to and act in new situations. Strive to protect the environment.
4. Biological and Bioorganic Chemistry	Know structure of enzymes as biological catalysts of protein nature. Classify enzymes.

4. Tasks for independent work during preparation for the class and in class.

4.1. The list of key terms, parameters, characteristics which the student is to learn while preparing for classes:

Term	Definition
1. Coordination compounds	These are compounds that have complex particles containing a central atom (ion) and its surrounding molecules (ions) in their crystal lattice.
2. Coordination number	The number of bonds by which ligands are bound directly to the central atom.
3. Denticity	This is the number of sites ligands occupy in the internal coordination sphere of the coordination complex.

4.2. Theoretical questions to the lesson:

1. Complexation reactions. Werner's coordination theory and modern concept of the structure of coordination compounds.
2. Classification of coordination compounds by the charge of the internal sphere and the nature of ligands.
3. Chelate compounds.
4. Coordination compounds in the boy that contain iron, cobalt, copper. A concept of metal-ligand homeostasis. Disturbances of the homeostasis.
5. Complexons and their use in medicine as antidotes at poisoning with heavy metals (chelatotherapy) and as antioxidants for preservation of drugs.
6. Trilon B and eugenol in dentistry.

Contents of the subject (abstract):

1. Modern concept of the structure of coordination compounds.

Coordination compounds are those that have complex particles containing a central atom (ion) and its surrounding molecules (ions) in their crystal lattice.

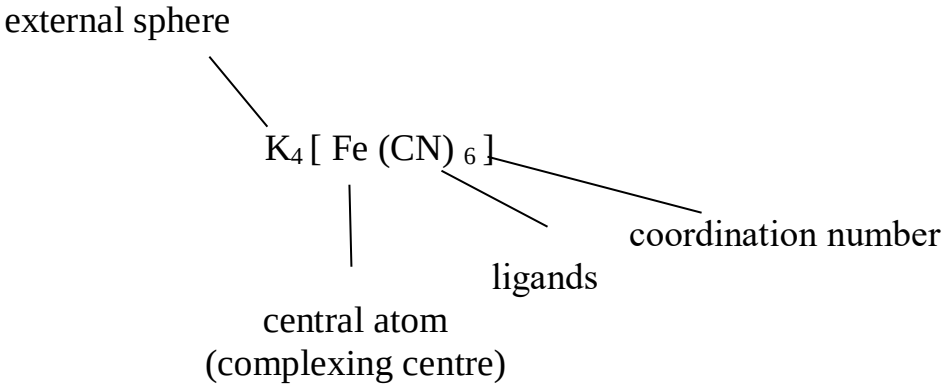
In 1893 Swiss chemist Werner developed a theory that explained the structure of coordination compounds.

In a coordination compound there is the central atom (ion) that is a complexing centre.

Ions, atoms or molecules (ligands) are coordinated around the central atom.

The complexing centre is bound to the ligands with donor-acceptor bonds. The central atom is the electron pair acceptor, the ligands are electron pair donors. The complexing centre and ligands form the internal sphere of the coordination complex. The internal sphere is denoted with brackets in formulas of coordination compounds.

The number of ligands coordinated around the central atom determines the coordination number that often takes values 2, 4, 6.



2. Classification of coordination compounds by the nature of ligands.

1. Complex compounds where ligands are molecules (water, ammonia, carbon (II) oxide):

a) aqua complexes:

$[Fe(\mathbf{H_2O})_6]Cl_3$ hexaaquaferric chloride. Ligands are molecules of water.

b) ammonia complexes:

$[Cu(\mathbf{NH_3})_4]SO_4$ tetraamminocupric sulfate. Ligands are molecules of water.

c) carbonyls:

$Fe(CO)_5$ iron pentacarbonyl.

2. Complex compounds where ligands are hydroxide ions – hydroxyl complexes:

$Na_3[Al(\mathbf{OH})_6]$ sodium hexahydroxyaluminate

3. Complex compounds where ligands are acidic ions (cyanide, etc.) – acidic complexes:

$K_3[Fe(\mathbf{CN})_6]$ potassium hexacyanoferrate (III).

4. Complex compounds where ligands are of different classes – mixed complexes:

$K[Al(\mathbf{OH})_4(\mathbf{H_2O})_2]$ potassium diaquatetrahydroxoaluminate.

Classification of coordination compounds by the charge of the internal sphere

1. Complex compounds with the complex cation:

$\mathbf{[Cu(NH_3)_4]^{2+}}SO_4^{2-}$ tetraamminocupric sulfate

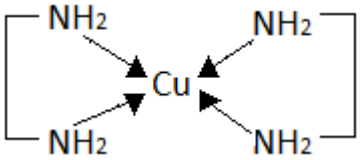
2. Complex compounds with the complex anion:
K_3^+**[Fe(CN)$_6$]$^{3-}$** potassium hexacyanoferrate (III)

3. Neutral complex compounds:
$Fe(CO)_5$ iron pentacarbonyl.

3. Chelate compounds

An important feature of ligands is their denticity or the number of places occupied by the ligand in the internal sphere.

When bidentate ligands are coordinated around the complexing agent, it results in formation of cyclic complexes. In such complex, a ligand and the complexing agent form a closed cycle due to bonds marked by arrows:



Complexes of this type are called internal complex compounds or chelates (from the Greek word "chela" that means a crab claw).

The structure of these compounds resembles crab claws with which that molecules of organic ligand capture ions of metals. Chelate complexes are formed in interaction of metal ions with aminocarboxylic acids and their derivatives; chelate compounds are used in chelatometry analyses and in chelatotherapy.

4. Concept of metal-ligand homeostasis. Disturbances of homeostasis.

The constant exchange with the environment enables the body to maintain a certain level of concentrations of the substances involved in equilibrium complexation processes, thus ensuring maintenance of metal-ligand homeostasis.

Each biometal has its metal-bioligand equilibrium state that is stipulated by stability of the complexes and by concentrations of both the metal and its biologands in the body.

There are many pathologies associated with excess or shortage of bioelements in the body.

Disturbances of metal-ligand homeostasis are possible for various reasons, including:

- deficiency or excess of bioelements;
- poisoning with cations of toxic metals;
- formation of uncharacteristic ligands;
- poisoning with xenobiotics.

Thus, excess or deficiency of essential metals in the body, poisoning with heavy metals and their compounds, toxic ligands, xenobiotics, viruses disturb metal-ligand homeostasis, which leads to pathological processes in the body.

5. Complexons and their use in medicine as antidotes at poisoning with heavy metals (chelatotherapy) and as antioxidants for preservation of drugs.

Complexons are polydentate ligands, e.g polyaminocarboxylic acids. Nitriloacetic acid (NTA) and ethylenediaminetetraacetic acid (EDTA) are important complexons.In medicine, they are used as antidotes at poisoning with heavy metals (chelatotherapy). Complexons bind ions of toxic metals and are excreted by the kidneys.

In medical practice, salts of EDTA are most often used as antidotes. The most widely used is disodium EDTA known as Trilon B. Mechanism of action of Trilon B at poisoning with Pb^{2+} can be represented as follows:

Trilon Б $\xrightarrow{Ca^{2+}}$ Tetacin $\xrightarrow{Pb^{2+}}$ CaPbEDTA

The complex CaPbEDTA is soluble in water and removed from the body by the kidneys. Tetacin is a universal antidote.

6. Trilon B and eugenol in dentistry

Some complexons or chelates have affinity to the mineral components of the tooth and form loose structures with them in a chemical reaction. Derivatives of EDTA are most often used in endodontics. These are disodium EDTA and tetracalcium EDTA. Because of their low surface tension these substances penetrate the narrowest root canals.

In practice, 10-20% neutral or slightly alkaline solutions of salts of EDTA salts are most often used. Eugenol is widely used in orthopedic and therapeutic dentistry (mixed with zinc oxide). The mixture is called zinc-eugenol cement. It is used as an insulating and treatment, temporary filling material. Dentists also often use it in clove oil.

Materials for self control:

A. Tasks for self control

1. Coordination number is:

a) the number of bonds of the ligands with the central atom;

b) number of sites, occupied by the ligands in the internal coordination sphere of the complex;

c) number of particles in one mole of a substance;

d) number of nuclons in the nucleus.

2. Which of the following ions Fe^{2+}, Fe^{3+}, Cl^-, HCO_3^-, K^+, Ca^{2+}, Na^+, Cu^{2+}, Zn^{2+} are complexing agents in enzymes:

a) K^+, Na^+, Cl^-; b) K^+, Ca^{2+}, Na^+; c) Fe^{2+}, Fe^{3+}, Ca^{2+}, Cu^{2+}, Zn^{2+}; d)Cl^-, HCO_3^-.

B. Practical tasks for self control:

1. Choose the central atom, its oxidation level, the coordination number and the charge of the coordination ion in the compound $K[Cr(H_2O)_2(CN)_4]$:

a) K, +1, 4, –1; b) Cr, +3, 6, –1; c) H_2O, 0, 6, –1; d) Cr, +2, 4, 0.

Literature

Main:

1. Medical Chemistry: textbook / V.O. Kalibabchuk, V.I. Halynska, V.I. Hryshchenko et al.; edited by Prof. V.O. Kalibabchuk – Kyiv: “Medicine”, 2010 – 224 p. (P. 16 – 23).

Informational resources:

2. www. pdmu, edu.ua
https://med-chemistry.pdmu.edu.ua/

(Web page of Poltava State Medical University).