Federal State Autonomous Educational Institution of Higher Education "Moscow Institute of Physics and Technology (National Research University)"

APPROVED
Head of Landau Phystech-School of Physics & Research
A.V. Rogachev

Work program of the course (training module)

course:	X-ray Crystallography of Membrane Proteins/Рентгеновская кристаллография мембранных белков
major:	Applied Mathematics and Physics
specialization:	General and Applied Physics/Общая и прикладная физика
	Landau Phystech-School of Physics & Research
	Chair of Biophysics
term:	1
qualification:	Master

Semester, form of interim assessment: 2 (spring) - Grading test

Academic hours: 30 AH in total, including:
lectures: 15 AH.
seminars: 15 AH.
laboratory practical: 0 AH.

Independent work: 60 AH.

In total: 90 AH, credits in total: 2

Number of course papers, tasks: 2

Author of the program: A.V. Rogachev, candidate of physics and mathematical sciences

The program was discussed at the Chair of Biophysics 19.06.2023

Annotation

X-ray crystallography is one of the main methods for determining the three-dimensional structure of biopolymers, in particular proteins. Thanks to this method, the structures of many enzymes and receptors important for pharmacology were obtained, which made it possible to understand the fundamental principles underlying the functioning of these molecular machines, and to apply this information, among other things, to the development of drug molecules that affect these proteins.

This course will introduce students to the principles and methods of the physics of neutron and X-ray scattering and their practical application in solid state physics and separately in relation to the field of structural biology. The basic principles of modern crystallography, the physical foundations of X-ray diffraction, the experimental technique and approaches to the analysis of its results will be presented.

The course is based on such areas of knowledge as crystallography, crystal chemistry, atomic and nuclear physics, analytical geometry.

1. Study objective

Purpose of the course

familiarization of students with the principles and methods of the physics of neutron and X-ray scattering and their practical use in the field of structural biology, the formation of special competencies in the field of using crystallography for scientific work in the field of structural and functional characterization of biological systems.

Tasks of the course

1) To form knowledge on the theory and physical principles of X-ray and neutron scattering.
2) Give ideas about geometric crystallography, the basics of crystal chemistry and crystal physics.
3) Formation of basic knowledge on the crystallization of water-soluble and membrane proteins.
4) Studying the principles of organization of protein crystals and conducting experiments on protein crystallization.
5) Formation of knowledge about the method of X-ray diffraction analysis of protein molecules.
6) Formation of practical skills in handling protein crystals and collecting diffraction data from them.
7) Formation of knowledge in the field of calculating the strategy for collecting crystallographic data, as well as determining the structure of proteins, refining the model and validating the results obtained.
8) Formation of knowledge about the method of studying proteins in solution by neutron and X-ray scattering methods.
9) Formation of skills for applying the acquired knowledge in independent, including research, work, problem solving, as well as analysis of the results obtained.

2. List of the planned results of the course (training module), correlated with the planned results of the mastering the educational program

Mastering the discipline is aimed at the formation of the following competencies:

Code and the name of the competence	Competency indicators
UC-1 Use a systematic approach to critically analyze a problem,and develop an action plan	UC-1.1 Systematically analyze the problem situation, identify its components and the relations between them
UC-6 Determine priorities and ways to improve performance through self-assessment	UC-6.1 Achieve personal growth and professional development, determine priorities and ways to improve performance
Gen.Pro.C-1 Gain fundamental scientific knowledge in the field of physical and mathematical sciences	Gen.Pro.C-1.1 Apply fundamental scientific knowledge in the field of physical and mathematical sciences
	Gen.Pro.C-1.2 Consolidate and critically assess professional experience and research findings
Gen.Pro.C-2 Acquire an understanding of current scientific and technological challenges	Gen.Pro.C-2.1 Assess the current state of mathematical research within professional settings
	Gen.Pro.C-2.2 Assess the relevance and practical importance of research in professional settings

in professional settings, and scientifically formulate professional objectives	Gen.Pro.C-2.3 Understand professional terminology used in modern scientific and technical literature and present scientific results in oral and written form within professional communication
Gen.Pro.C-4 Successfully perform a task, analyze the results, and present conclusions, apply knowledge and skills in the field of physical and mathematical sciences and ICTs	Gen.Pro.C-4.2 Apply knowledge in the field of physical and mathematical sciences to solve problems, make conclusions, and evaluate the obtained results
	Gen.Pro.C-4.3 Justify the chosen method of scientific research
Pro.C-1 Assign, formalize, and solve tasks, develop and research mathematical models of the studied phenomena and processes, systematically analyze scientific problems and obtain new scientific results	Pro.C-1.1 Locate, analyze, and summarize information on current research findings within the subject area
	Pro.C-1.3 Apply theoretical and/or experimental research methods to a specific scientific task and interpret the obtained results
Pro.C-2 Organize and conduct scientific research and testing independently or as a member (leader) of a small research team	Pro.C-2.1 Plan and conduct scientific research independently or as part of a research team

3. List of the planned results of the course (training module)

As a result of studying the course the student should:

know:

1) the theory of X-ray diffraction on crystalline structures and polycrystalline samples;
2) the chemical structure of proteins, their elements of the secondary structure;
3) the principles of operation of various methods of crystallization of water-soluble proteins, the phase diagram of crystallization;
4) the device of a biological membrane, what are membrane proteins;
5) the complexity of working with membrane proteins;
6) methods of crystallization of membrane proteins in a detergent solution, types of crystals;
7) principles of approach to the crystallization of membrane proteins using lipid phases, monoolein/water phase diagram;
8) principles of optimization of crystallization conditions;
9) stages of solving three-dimensional structures of proteins by X-ray diffraction analysis;
10) principles of collecting crystallographic data;
11) tools for working with crystallographic data and determining the spatial structure of a protein;
12) methods for solving the phase problem;
13) principles of studying the spatial organization of protein molecules by the method of small-angle X-ray scattering.

be able to:

1) apply experimental methods of X-ray diffraction analysis and scattering methods;
2) prepare a protein preparation for crystallization;
3) to conduct an experiment on protein crystallization;
4) analyze and optimize the crystallization protocol;
5) to conduct a diffraction experiment;
6) work with crystallographic software packages.

master:

1) methods of applying the main laws of diffraction, the main methods of analyzing the diffraction pattern;
2) methods of crystallization of water-soluble proteins;
3) methods of crystallization of membrane proteins in a detergent solution and in lipid mesophases;
4) skills of working on an automated crystallization system;
5) skills in working on an automated system for monitoring crystallization samples;
6) a technique for preparing the grown crystals for a diffraction experiment;
7) a technique for collecting diffraction data from a protein crystal;
8) practical skills in calculating the data collection strategy, integrating and scaling data;
9) practical skills in determining the spatial structure of a protein;
10) a technique for conducting an experiment on small-angle X-ray scattering.

4. Content of the course (training module), structured by topics (sections), indicating the number of allocated academic hours and types of training sessions

4.1. The sections of the course (training module) and the complexity of the types of training sessions

№	Topic (section) of the course	Types of training sessions, including independent work			
		Lectures	Seminars	Laboratory practical	Independent work
1	Geometric crystallography	1	1		4
2	Fundamentals of crystal chemistry and crystal physics	2	2		8
3	Diffraction on crystals	2	2		8
4	Physics of x-rays. Basic methods of X-ray diffraction analysis	2	2		8
5	Fundamentals of Neutron Scattering Physics	1	1		4
6	Theory of intensity of diffraction scattering by crystals	2	2		8
7	Protein crystallization	1	1		4
8	Acquisition of diffraction data	2	2		8
9	Determination of the spatial structure of a protein	2	2		8
AH in total		15	15		60
Exam preparation		0 AH.			
Total complexity		90 AH., credits in total 2			

4.2. Content of the course (training module), structured by topics (sections)

Semester: 2 (Spring)

1. Geometric crystallography

The concept of a crystal. Crystal projections. Elementary cell, categories and syngonies. Indices of planes and directions. Elements of symmetry and their interaction. Symmetry classes (point groups). General and private provisions. Symmetry of the discontinuum. Brave broadcast system. Basis. Spatial groups. Correct point systems.

2. Fundamentals of crystal chemistry and crystal physics

Atomic (ionic) radius. Dense packings, their pores. Representation of the structure through dense packings, coordination polyhedra and networks. The concept of a structural type. Standard structure type information. Basic structural types of elements and compounds.
Elements of crystal physics. Curie-Neumann principle. Limit symmetry groups. The principle of tensor description of the physical properties of a crystal.

3. Diffraction on crystals

Scattering by small crystals. interference function. Laue equation. Wulf-Bragg equation. Interference indices. Reciprocal lattice as a periodic distribution of interference maxima.
The radius vector of the reciprocal lattice and its properties. The connection of the reciprocal lattice with the structure, size and shape of the crystal.
Geometric interpretation of the Laue equation (Ewald's construction). Principles of the main methods of X-ray diffraction analysis.

4. Physics of x-rays. Basic methods of X-ray diffraction analysis

Obtaining and properties of x-rays. X-ray spectra. Interaction of X-rays with matter. Methods for registering X-ray radiation. Methods for the study of single crystals (Laue method, rotation method). Concept of diffraction symmetry class. polycrystal method. Obtaining and calculating radiographs. Indexing of radiographs. X-ray diffractometry. Monochromatization of X-rays.

5. Fundamentals of Neutron Scattering Physics

Scattering of X-rays by an electron and an atom. Atomic scattering function. Scattering by a non-primitive cell. Structural amplitude. Integral, zonal and serial extinctions. Influence of absorption and thermal oscillations on the intensity of interference maxima. Formulas for calculating the integral intensity in kinematic theory.

6. Theory of intensity of diffraction scattering by crystals

Conclusion of the integral intensity (power) of scattering by single- and polycrystals. Fundamentals of the dynamical theory of X-ray scattering. Extinction. Peculiarities of scattering of fast electrons and thermal neutrons by crystals. Obtaining diffraction spectra of electron and neutron scattering. Application of neutron diffraction patterns for the analysis of the crystal structure of matter.

7. Protein crystallization

Physical and chemical bases of crystallization of macromolecules. Technical methods of crystallization of water-soluble proteins. Biological membranes, membrane proteins. Features of handling membrane proteins. Crystallization of membrane proteins in detergent solution, type I and type II crystals of membrane proteins. Crystallization of membrane proteins using lipid mesophases. Phase diagram of monoolein/water. The mechanism of crystallization of membrane proteins in the lipid cubic phase. Automated crystallization systems. Evaluation of the results of a crystallization experiment, optimization of crystallization conditions.

8. Acquisition of diffraction data

Preparation of crystals for taking diffraction data. Cryoprotection. Experimental technique for taking diffraction data. Positioning of the crystal on the x-ray machine. Strategy and main data collection parameters. Processing of experimental data. Determination of elementary lattice parameters, crystal indexing. Determination of the number of molecules in an elementary cell. Refinement of Laue and the space group of the crystal. Set completeness for the refined space group. Calculation of the strategy for collecting diffraction data. Integration of diffraction data on the example of crystallographic data of lysozyme and bacteriorhodopsin. Data scaling.

9. Determination of the spatial structure of a protein

Phase problem. Molecular substitution method. Selection of the starting model from databases of three-dimensional macromolecular structures. Critical parameters when using the rotation and translation function. Method of anomalous scattering. Solution of the phase problem by the method of molecular substitution on the example of crystallographic data of lysozyme and bacteriorhodopsin. Interpretation of electron density maps and construction of a macromolecule model. Refinement of the structure model using stereochemical and energy constraints, refinement parameters. Analysis of the correctness of the geometry and stereochemistry of the refined model of the structure of macromolecules. Automated construction of protein structures. Refinement of the structures of lysozyme and bacteriorhodopsin. The study of electron density maps. Validation of the obtained structures.

5. Description of the material and technical facilities that are necessary for the implementation of the educational process of the course (training module)

The theoretical part of the course will be taught in a classroom equipped with a multimedia projector and screen, or using distance learning using both videoconferencing technologies using videoconferencing software (Zoom, Skype, etc.), webinar systems (BigBlueButton, Google Meet etc.), and using MIPT resources, including the lms.mipt.ru system and the MIPT self-recording studio.
The practice-oriented part of the course will be conducted using equipment for biochemical and biophysical research, based at the Center for Research on the Molecular Mechanisms of Aging and Age-Related Diseases.
1. Platform for genetic engineering, preparative expression and purification of membrane proteins. The platform includes an instrument base for genetic engineering, incubator shakers and fermenters for cultivating cultures of bacterial and yeast producing strains, preparative and ultracentrifuges, a preparative microfluidizer and a French press for cell lysis, chromatographic systems, systems for DNA and protein electrophoresis , as well as the necessary small laboratory equipment.
2. Platform for high-throughput in meso membrane protein crystallization includes a set of innovative Formulatrix instruments for membrane protein crystallization and crystal visualization.
3. Platform for protein crystallography and X-ray scattering based on Rigaku HighFlux HomeLab includes Equipment for in-house X-ray diffraction experiment.
4. Computing power for data processing of diffraction and spectroscopic measurements. There are local computer clusters to perform computer simulations. Employees have constant access to the resources of the MIPT data center, which provides server equipment for sharing (including the allocation of virtual servers and access to a common computing cluster). There is access to the computing CPU cluster at the Center for Free Electron Laser science (CFEL, Hamburg, Germany) with 132 CPU cores, as well as a system of priority access to calculations during the experiment. The possibility of post-processing and data storage on a computing cluster based on the Korean PAL XFEL (72 CPU cores).

6. List of the main and additional literature, that is necessary for the course (training module) mastering

Main literature

1. Основы кристаллографии [Текст] : учеб. пособие для вузов / Е. В. Чупрунов, А. Ф. Хохлов, М. А. Фаддеев .— М. : Физматлит, 2004 .— 500 с.

2. Физика белка : Курс лекций с цветными стереоскопическими иллюстрациями и задачами [Текст] / А. В. Финкельштейн, О. Б. Птицын - М.КДУ,2014

3. Синхротронное излучение. Методы исследования структуры веществ [Текст] / Г. В. Фетисов - М.Физматлит,2007

4. Современная кристаллография [Текст] : в 4 т. Т. 4/Л. А. Шувалов [и др.] , -М., Наука, 1981

5. Принципы структурной организации белков [Текст]/Г. Е. Шульц, Р. Х. Ширмер , -М., Мир, 1982

6. В.И. Иверонова, Г.П. Ревкевич. Теория рассения рентгеновских лучей. М., МГУ, 1978.
7. В.Ш.Шехтман, Р.А.Диланян. Введение в рентгеновскую кристаллографию. Черноголовка, 2002.
8. T. L. Blundell, L. Johnson. Protein Crystallography (Molecular Biology Series), Academic Press, 1976.
9. Alberts B., Johnson A. et al. Molecular Biology of the Cell, 5th ed., Garland Science, N. Y. 2008.
10. Д.И. Свергун, Л.А. Фейгин, Рентгеновское и нейтронное малоугловое рассеяние, - М.: Наука, Главная редакция Физ-Мат Литературы, 1986 – 278 с.

Additional literature

1. Кристаллография [Текст] : учеб. пособие для вузов / М. П. Шаскольская .— 2-е изд., перераб. и доп. — М. : Высшая школа, 1984 .— 375 с.

2. Биофизика [Текст] : [учеб. пособие для вузов] / М. В. Волькенштейн .— 2-е изд., перераб. и доп. — М. : Наука, 1988 .— 592 с.

3. Биофизика [Текст] : в 2 т. Т. 1 : учебник для вузов. Теоретическая биофизика / А. Б. Рубин ; Моск. гос. ун-т им. М. В. Ломоносова .— 3-е изд., испр. и доп. — М. : Изд-во МГУ : Наука, 2004 .— 448 с.

4. Биофизика [Текст] : в 2 т. Т. 2 : учебник для вузов. Биофизика клеточных процессов / А. Б. Рубин ; Моск. гос. ун-т им. М. В. Ломоносова .— 3-е изд., испр. и доп. — М. : Изд-во МГУ : Наука, 2004 .— 469 с.

5. А. И. Китайгородский. Рентгеноструктурный анализ. М., Гостехиздат, 1950
6. С. С. Горелик, Л. Н. Расторгуев, Ю. А. Скаков. Рентгенографический и электроннографический анализ. М., Металлургия, 1970

7. List of web resources that are necessary for the course (training module) mastering

Открытые базы данных химической и медико-биологической информации (Chembl, drugbank, gencards, pubmed, GEO)

8. List of information technologies used for implementation of the educational process, including a list of software and information reference systems (if necessary)

When preparing and conducting lectures, the Internet is used.

9. Guidelines for students to master the course

A student studying the discipline must, on the one hand, master the general conceptual apparatus, and on the other hand, must learn to apply theoretical knowledge in practice.

As a result of studying the discipline, the student must know the basic definitions and concepts, be able to apply the knowledge gained to solve various problems.

Successful completion of the course requires:
- attendance of all classes provided for by the curriculum for the discipline;
- keeping a synopsis of classes;
- student's intense independent work.

Independent work includes:
- reading recommended literature;
- study of educational material, preparation of answers to questions intended for independent study;
- solving problems offered to students in the classroom;
- preparation for the performance of tasks of the current and intermediate certification.

An indicator of mastery of the material is the ability to answer questions on the topics of the discipline without a synopsis.

It is important to achieve an understanding of the material being studied, not its mechanical memorization. If a student finds it difficult to study certain topics, questions, he/she should seek advice from a teacher.

Intermediate control of students' knowledge is possible in the form of solving problems in accordance with the topic of classes.

SUPPLEMENT

Assessment funds for course (training module)

major:	Applied Mathematics and Physics
specialization:	General and Applied Physics/Общая и прикладная физика Landau Phystech-School of Physics & Research Chair of Biophysics
term:	1
qualification:	Master

Semester, form of interim assessment: 2 (spring) - Grading test

Author: A.V. Rogachev, candidate of physics and mathematical sciences

1. Competencies formed during the process of studying the course

Code and the name of the competence	Competency indicators
UC-1 Use a systematic approach to critically analyze a problem,and develop an action plan	UC-1.1 Systematically analyze the problem situation, identify its components and the relations between them
UC-6 Determine priorities and ways to improve performance through self-assessment	UC-6.1 Achieve personal growth and professional development, determine priorities and ways to improve performance
Gen.Pro.C-1 Gain fundamental scientific knowledge in the field of physical and mathematical sciences	Gen.Pro.C-1.1 Apply fundamental scientific knowledge in the field of physical and mathematical sciences
	Gen.Pro.C-1.2 Consolidate and critically assess professional experience and research findings
Gen.Pro.C-2 Acquire an understanding of current scientific and technological challenges in professional settings, and scientifically formulate professional objectives	Gen.Pro.C-2.1 Assess the current state of mathematical research within professional settings
	Gen.Pro.C-2.2 Assess the relevance and practical importance of research in professional settings
	Gen.Pro.C-2.3 Understand professional terminology used in modern scientific and technical literature and present scientific results in oral and written form within professional communication
Gen.Pro.C-4 Successfully perform a task, analyze the results, and present conclusions, apply knowledge and skills in the field of physical and mathematical sciences and ICTs	Gen.Pro.C-4.2 Apply knowledge in the field of physical and mathematical sciences to solve problems, make conclusions, and evaluate the obtained results
	Gen.Pro.C-4.3 Justify the chosen method of scientific research
Pro.C-1 Assign, formalize, and solve tasks, develop and research mathematical models of the studied phenomena and processes, systematically analyze scientific problems and obtain new scientific results	Pro.C-1.1 Locate, analyze, and summarize information on current research findings within the subject area
	Pro.C-1.3 Apply theoretical and/or experimental research methods to a specific scientific task and interpret the obtained results
Pro.C-2 Organize and conduct scientific research and testing independently or as a member (leader) of a small research team	Pro.C-2.1 Plan and conduct scientific research independently or as part of a research team

2. Competency assessment indicators

As a result of studying the course the student should:

know:

1) the theory of X-ray diffraction on crystalline structures and polycrystalline samples;
2) the chemical structure of proteins, their elements of the secondary structure;
3) the principles of operation of various methods of crystallization of water-soluble proteins, the phase diagram of crystallization;
4) the device of a biological membrane, what are membrane proteins;
5) the complexity of working with membrane proteins;
6) methods of crystallization of membrane proteins in a detergent solution, types of crystals;
7) principles of approach to the crystallization of membrane proteins using lipid phases, monoolein/water phase diagram;
8) principles of optimization of crystallization conditions;
9) stages of solving three-dimensional structures of proteins by X-ray diffraction analysis;
10) principles of collecting crystallographic data;
11) tools for working with crystallographic data and determining the spatial structure of a protein;
12) methods for solving the phase problem;
13) principles of studying the spatial organization of protein molecules by the method of small-angle X-ray scattering.

be able to:

1) apply experimental methods of X-ray diffraction analysis and scattering methods;
2) prepare a protein preparation for crystallization;
3) to conduct an experiment on protein crystallization;
4) analyze and optimize the crystallization protocol;
5) to conduct a diffraction experiment;
6) work with crystallographic software packages.

master:

1) methods of applying the main laws of diffraction, the main methods of analyzing the diffraction pattern;
2) methods of crystallization of water-soluble proteins;
3) methods of crystallization of membrane proteins in a detergent solution and in lipid mesophases;
4) skills of working on an automated crystallization system;
5) skills in working on an automated system for monitoring crystallization samples;
6) a technique for preparing the grown crystals for a diffraction experiment;
7) a technique for collecting diffraction data from a protein crystal;
8) practical skills in calculating the data collection strategy, integrating and scaling data;
9) practical skills in determining the spatial structure of a protein;
10) a technique for conducting an experiment on small-angle X-ray scattering.

3. List of typical control tasks used to evaluate knowledge and skills

In order to control the students' mastery of the training material, an oral questioning is conducted at the beginning of the lesson on the topic of the last session.

4. Evaluation criteria

Checking questions:

1. X-ray diffraction on various objects: electron, electron gas, atom, monatomic gas and liquid, crystals.
2. Crystal lattice: nodes, directions and planes. Crystallographic point and space symmetry groups. Crystal structure of elements and simple compounds.
3. Structural amplitude of various crystal structures. Manifestation of crystal symmetry in the array {Fhkl2}.
4. Experimental methods for measuring the array {Fhkl2}.
5. Solution of the inverse problem: determination of the electron density ρ(r) of the crystal from the measured array {Fhkl2}. Patterson function, heavy atom method. Fourier synthesis of electron density. Determination of phases of structural amplitudes: statistical analysis of the array {Fhkl2}, isomorphic substitution.
6. Fundamentals of crystal chemistry and crystal physics
7. Diffraction on crystals
8. Physics of x-rays. Basic methods of X-ray diffraction analysis
9. Fundamentals of Neutron Scattering Physics
10. Theory of intensity of diffraction scattering by crystals

Checking tasks:

A selection and analysis of the material is being prepared using the example of solving the structure of proteins according to the following scheme:

1. Target is selected http://pdb101.rcsb.org/motm/motm-by-date
2. A selection of articles on the selected target is made.

If this is a class of proteins, then one of the most interesting representatives is selected.

Contents of scientific articles: solution of the structure of the selected target by crystallography and/or cryoelectron microscopy.

3. A selection of articles, if possible, should include material on obtaining the structure by several methods and / or with different resolutions for different conditions.
4. Based on the selected articles on the target selected in paragraph 1, an annotated description (abstract) is prepared.

The abstract should include: target selection; relevance; expression; purification, characterization (from various articles); crystallization if the structure was solved by XRD; crystallography; grobopreparation in the case of cryoelectron microscopy; description of the cryoelectron microscopy experiment; generalized conclusions about the structure of the target, the features of the structure that were revealed in different works.

5. A report is presented on the material of the abstract lasting 10-15 minutes.

Assessment “excellent (10)” is given to a student who has displayed comprehensive, systematic and deep knowledge of the educational program material, has independently performed all the tasks stipulated by the program, has deeply studied the basic and additional literature recommended by the program, has been actively working in the classroom, and understands the basic scientific concepts on studied discipline, who showed creativity and scientific approach in understanding and presenting educational program material, whose answer is characterized by using rich and adequate terms, and by the consistent and logical presentation of the material;

Assessment “excellent (9)” is given to a student who has displayed comprehensive, systematic knowledge of the educational program material, has independently performed all the tasks provided by the program, has deeply mastered the basic literature and is familiar with the additional literature recommended by the program, has been actively working in the classroom, has shown the systematic nature of knowledge on discipline sufficient for further study, as well as the ability to amplify it on one’s own, whose answer is distinguished by the accuracy of the terms used, and the presentation of the material in it is consistent and logical;

Assessment “excellent (8)” is given to a student who has displayed complete knowledge of the educational program material, does not allow significant inaccuracies in his answer, has independently performed all the tasks stipulated by the program, studied the basic literature recommended by the program, worked actively in the classroom, showed systematic character of his knowledge of the discipline, which is sufficient for further study, as well as the ability to amplify it on his own;

Assessment “good (7)” is given to a student who has displayed a sufficiently complete knowledge of the educational program material, does not allow significant inaccuracies in the answer, has independently performed all the tasks provided by the program, studied the basic literature recommended by the program, worked actively in the classroom, showed systematic character of his knowledge of the discipline, which is sufficient for further study, as well as the ability to amplify it on his own;

Assessment “good (6)” is given to a student who has displayed a sufficiently complete knowledge of the educational program material, does not allow significant inaccuracies in his answer, has independently carried out the main tasks stipulated by the program, studied the basic literature recommended by the program, showed systematic character of his knowledge of the discipline, which is sufficient for further study;

Assessment “good (5)” is given to a student who has displayed knowledge of the basic educational program material in the amount necessary for further study and future work in the profession, who while not being sufficiently active in the classroom, has nevertheless independently carried out the main tasks stipulated by the program, mastered the basic literature recommended by the program, made some errors in their implementation and in his answer during the test, but has the necessary knowledge for correcting these errors by himself;

Assessment “satisfactory (4)” is given to a student who has discovered knowledge of the basic educational program material in the amount necessary for further study and future work in the profession, who while not being sufficiently active in the classroom, has nevertheless independently carried out the main tasks stipulated by the program, learned the main literature but allowed some errors in their implementation and in his answer during the test, but has the necessary knowledge for correcting these errors under the guidance of a teacher;

Assessment “satisfactory (3)” is given to a student who has displayed knowledge of the basic educational program material in the amount necessary for further study and future work in the profession, not showed activity in the classroom, independently fulfilled the main tasks envisaged by the program, but allowed errors in their implementation and in the answer during the test, but possessing necessary knowledge for elimination under the guidance of the teacher of the most essential errors;

Assessment “unsatisfactory (2)” is given to a student who showed gaps in knowledge or lack of knowledge on a significant part of the basic educational program material, who has not performed independently the main tasks demanded by the program, made fundamental errors in the fulfillment of the tasks stipulated by the program, who is not able to continue his studies or start professional activities without additional training in the discipline in question;

Assessment “unsatisfactory (1)” is given to a student when there is no answer (refusal to answer), or when the submitted answer does not correspond at all to the essence of the questions contained in the task.

5. Methodological materials defining the procedures for the assessment of knowledge, skills, abilities and/or experience

The course is graded at a credit. The questioning starts with a random task assigned to each student and time given for completion of the task. No aids are allowed. The student then proceeds to a chat with the examiner, at which he/she presents his/her solution to the assigned task. The examiner then asks the student several questions that evenly cover the course content. A final grade is assigned based on the quality of answers and demonstrated level of understanding.