

**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:** Mathematical and Computational Approaches to Neural Function/Математические и  
вычислительные подходы к функционированию нервной системы

**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: 30 AH.

seminars: 0 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: I.V. Manukhov, doctor of biological sciences

The program was discussed at the Chair of Biophysics 25.08.2022

## Annotation

Understanding the mechanisms of brain function is a major challenge for the 21st century. In this course, we will explore mathematical and computational approaches to studying the biophysics of neural dynamics and how these lead to emergent neuronal network phenomena. We will further survey computational models of how neural circuit dynamics produce brain computations and cognitive functions. We will give a special focus to learning and plasticity processes and their modulation through the aging process.

### 1. Study objective

#### Purpose of the course

formation and improvement of students' competencies in the field of mathematical and computational approaches to the study of biophysics of neural dynamics and neural networks.

#### Tasks of the course

- 1) Acquaintance of students with mathematical and computational approaches to the study of biophysics of neural dynamics
- 2) Acquaintance students with computational models of how the dynamics of neural circuits produces calculations in the brain and cognitive functions

### 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-1.2 Search for solutions by using available sources
	UC-1.3 Develop a step-by-step strategy for achieving a goal, foresee the result of each step, evaluate the overall impact on the planned activity and its participants
UC-4 Use modern communication tools in the academic and professional fields, including those in a foreign language	UC-4.1 Exchange business information in oral and written forms in Russian and at least one foreign language
	UC-4.4 Use modern ICT tools for academic and professional collaboration
	UC-4.2 Use the acquired skills to write, translate, and edit various academic texts (abstracts, essays, reviews, articles, etc.)
	UC-4.3 Present the results of academic and professional activities at various academic events, including international conferences
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-3.1 Analyze problems, plan research strategy to achieve solution(s), propose, and combine solution approaches

Gen.Pro.C-3 Select and/or develop approaches to professional problem-solving with consideration to the limitations and specifics of different solution methods	Gen.Pro.C-3.2 Employ research methods to solve new problems and apply knowledge from various fields of science (technology)
	Gen.Pro.C-3.3 Gain knowledge of analytical and computational methods of problem-solving, understand the limitations of the implementation of the obtained solutions in practice
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-4.1 Apply ICT knowledge and skills to find and study scientific literature and use software products
	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-1.2 Make hypotheses, build mathematical models of the studied phenomena and processes, evaluate the quality of the developed model
	Pro.C-1.3 Apply theoretical and/or experimental research methods to a specific scientific task and interpret the obtained results
Pro.C-3 Use research and testing equipment (devices and installations, specialized software) in a selected subject field	Pro.C-3.1 Understand the operating principles of the equipment and specialized software
	Pro.C-3.2 Conduct an experiment (simulation) using research equipment (software)
	Pro.C-3.3 Evaluate the accuracy of the experimental (numerical) results

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

As a result of studying the course the student should:

know:

- 1) Basic mathematical and computational approaches to the study of biophysics of neural dynamics
- 2) Modern computational models of how the dynamics of neural circuits produces calculations in the brain and cognitive functions

be able to:

- 1) Apply mathematical and computational approaches to the study of biophysics of neural dynamics to solve fundamental professional problems;
- 2) Creatively use in scientific activity knowledge about the possibilities of applying modern methods of biophysics;
- 3) Highlight and systematize the main ideas in scientific texts;
- 4) Critically evaluate any incoming information, regardless of the source;
- 5) Generate new ideas and methodological solutions;
- 6) Carry out the design of their scientific activities;
- 7) Present your scientific results in oral reports.

master:

- 1) Methods of theoretical and experimental research;
- 2) Skills of search (including using information systems and databases), processing, analysis and systematization of information;
- 3) Skills of critical analysis and assessment of modern scientific achievements.

### 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	Modelling Behavior I	2			5
2	Modelling Behavior II	2			5
3	Neural Decoding	2			5
4	Neural Decision Making	2			5
5	Neural Encoding	4			5
6	Networks and Learning	4			5
7	Biophysics of Neurons I	2			5
8	Biophysics of Neurons II	2			5
9	Neural Bursters	2			5
10	Neural Oscillations I	2			5
11	Neural Oscillations II	2			5
12	Approaches to Neural Stochastic Models	4			5
AH in total		30			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. Modelling Behavior I

Reinforcement models of behavior

##### 2. Modelling Behavior II

Models of behavioral pathologies

##### 3. Neural Decoding

Mathematical models of decoding sensory stimuli

##### 4. Neural Decision Making

Mathematical models of neural mechanisms of decision making

##### 5. Neural Encoding

Mathematical models of encoding sensory stimuli and receptive fields

##### 6. Networks and Learning

Computational models of neural network behavior and plasticity

##### 7. Biophysics of Neurons I

Models of neuronal excitability and spike generation

## 8. Biophysics of Neurons II

Mathematics of Neural Excitability

## 9. Neural Bursters

Multi-time scale dynamics of complex neural behaviors

## 10. Neural Oscillations I

Mathematical modelling of the emergence of single neuron oscillations and networks of neural oscillators

## 11. Neural Oscillations II

Mathematical approaches to analysis of emergence network oscillations

## 12. Approaches to Neural Stochastic Models

Mathematical analysis of noise induced neural dynamics

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

1. Classroom with a media projector and screen, Internet access.
2. Required software.
3. Providing independent work - databases on logs.

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

Main literature

Theoretical Neuroscience: Computational and Mathematical Modeling of Neural Systems. By Laurence F. Abbott and Peter Dayan, MIT Press.

Additional literature

Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting By Eugene M. Izhikevich

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

Not used

### **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.

In addition, Libre Office is used, as well as the Ink Scape graphics package.

### **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 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.

**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:** I.V. Manukhov, doctor of biological 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-1.2 Search for solutions by using available sources
	UC-1.3 Develop a step-by-step strategy for achieving a goal, foresee the result of each step, evaluate the overall impact on the planned activity and its participants
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	UC-4.4 Use modern ICT tools for academic and professional collaboration
	UC-4.2 Use the acquired skills to write, translate, and edit various academic texts (abstracts, essays, reviews, articles, etc.)
	UC-4.3 Present the results of academic and professional activities at various academic events, including international conferences
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-3 Select and/or develop approaches to professional problem-solving with consideration to the limitations and specifics of different solution methods	Gen.Pro.C-3.1 Analyze problems, plan research strategy to achieve solution(s), propose, and combine solution approaches
	Gen.Pro.C-3.2 Employ research methods to solve new problems and apply knowledge from various fields of science (technology)
	Gen.Pro.C-3.3 Gain knowledge of analytical and computational methods of problem-solving, understand the limitations of the implementation of the obtained solutions in practice
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-4.1 Apply ICT knowledge and skills to find and study scientific literature and use software products
	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	Pro.C-1.1 Locate, analyze, and summarize information on current research findings within the subject area
	Pro.C-1.2 Make hypotheses, build mathematical models of the studied phenomena and processes, evaluate the quality of the developed model



systematically analyze scientific problems and obtain new scientific results	Pro.C-1.3 Apply theoretical and/or experimental research methods to a specific scientific task and interpret the obtained results
Pro.C-3 Use research and testing equipment (devices and installations, specialized software) in a selected subject field	Pro.C-3.1 Understand the operating principles of the equipment and specialized software
	Pro.C-3.2 Conduct an experiment (simulation) using research equipment (software)
	Pro.C-3.3 Evaluate the accuracy of the experimental (numerical) results

## 2. Competency assessment indicators

As a result of studying the course the student should:

### know:

- 1) Basic mathematical and computational approaches to the study of biophysics of neural dynamics
- 2) Modern computational models of how the dynamics of neural circuits produces calculations in the brain and cognitive functions

### be able to:

- 1) Apply mathematical and computational approaches to the study of biophysics of neural dynamics to solve fundamental professional problems;
- 2) Creatively use in scientific activity knowledge about the possibilities of applying modern methods of biophysics;
- 3) Highlight and systematize the main ideas in scientific texts;
- 4) Critically evaluate any incoming information, regardless of the source;
- 5) Generate new ideas and methodological solutions;
- 6) Carry out the design of their scientific activities;
- 7) Present your scientific results in oral reports.

### master:

- 1) Methods of theoretical and experimental research;
- 2) Skills of search (including using information systems and databases), processing, analysis and systematization of information;
- 3) Skills of critical analysis and assessment of modern scientific achievements.

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

Examples of topics of individual courseworks:

Models of neural decision making: drift-diffusion models of decision coding

Models of neural receptive fields and sensory encoding.

Models of neuronal biophysics, integrate and fire neurons

Modeling neural bursters, slow-fast analysis

Dynamics of neuronal oscillations – simulations of PING vs ING

## 4. Evaluation criteria

Checking questions:

Reinforcement models of behavior

Reinforcement learning basics of Rescola-Wagner and policy formation

Reinforcement learning with temporal difference learning

Model-based reinforcement learning and policy optimization

Models of neural signal decoding and the ideal observer model

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.