**CONTEMPORARY PROBLEMS OF THEORETICAL PHYSICS**

**1. GENERAL CHARACTERISTICS OF THE DISCIPLINE**

The discipline programme is compiled in accordance with the Federal State Standards of Higher Education

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| --- | --- | --- | --- |
| Code of major | Major/direction | Details of the order of the Ministry of Education and Science of the Russian Federation on approval and putting into effect the Federal State Standards of Higher Education | |
| Date | Number of order |
| 03.06.01 | Physics and Astronomy/  01.04.02 - Theoretical physics 01.04.11- Physics of magnetic phenomena | 30 July 2014  With amendments dated 30 April 2015 | 867  Amendments  464 |

**1.1. Objectives of the discipline**

The objective of the Contemporary Problems of Theoretical Physics discipline is to acquire basic professional competences during an in-depth study of the problems and issues facing researchers at the present time in the field of theoretical physics.

**1.2. The discipline in the structure of the educational activities and the principal educational programme**

The Contemporary Problems of Theoretical Physics discipline refers to Section B.1 of the elective part of the Principal Educational Programme of the postgraduate course and is aimed at preparing for the qualifying examinations for the Ph.D. degree.

As a result of mastering the discipline, a student should master the following competences:

**Universal Competencies:**

the ability to critically analyse and evaluate current scientific achievements, generate new ideas for solving research and practical problems, also in inter-disciplinary areas (Universal Competence-1);

the ability to plan and solve their own professional and personal development problems (Universal Competence-5);

**Professional Competences:**

the ability to freely master the fundamental sections of physics necessary for solving research problems in areas corresponding to the chosen direction, i.e. theoretical physics, condensed matter physics, physics of magnetic phenomena, thermal physics and theoretical heat engineering (Professional Competence-1);

the ability to use the knowledge of contemporary problems of physics, the latest achievements of physics in their research activities (Professional Competence-2);

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Discipline** | **Semester** | **Period used to master the discipline** | | | | | | |
| **In-class learning** | | | | **Self-guided work** | **Discipline attestation (test, exam)** | **Hour/credit, total** |
| **Total** | **Lectures** | **Practical exercises** | **Laboratory work** |
| Contemporary Problems of Theoretical Physics | 5 | 4 | 4 |  |  | 104 | Test, semester 5 | 108/3 |
| **Period of mastering, total** | | **4** | **4** |  |  | **104** |  | **108/3** |

**3. CONTENTS OF THE DISCIPLINE**

**3.1 Scope and content of the discipline**

|  |  |  |  |
| --- | --- | --- | --- |
| **No** | **Subject, section** | **Work input** | |
| **Hours** | **Credits** |
| 1 | Section 1. Group-theoretical methods | 10 |  |
| 2 | Section 2. Theory of phase transitions and critical phenomena | 8 |  |
| 3 | Section 3. Elements of quantum statistical mechanics | 12 |  |
| 4 | Section 4. Many-Electron Atoms in Crystals | 12 |  |
| 5 | Section 5. Electronic theory of metal | 10 |  |
| 6 | Section 6. Methods of the band theory of crystals | 8 |  |
| 7 | Section 7. Vibrations of lattices, phonons | 10 |  |
| 8 | Section 8. Theory of superconductivity | 10 |  |
| 9 | Section 9. Selected problems in the theory of low-dimensional systems | 10 |  |
| 10 | Section 10. Elements of the theory of disordered systems | 8 |  |
| 11 | Section 11 Standard models and methods of the theory of strongly correlated systems | 10 |  |
|  | **TOTAL** | **108** | **3** |

**3.2. Distribution of the amount of study time for the discipline by topic and type of work**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No | Subject, section of discipline | Amount of time assigned for the discipline study,credit/hour | | | | | | |
| In-class learning | | | | | Self-guided work | Section and subject, total |
| total | Including lectures | Including seminar/ practical exercises | | Including laboratory work |
| 1 | Section 1. Group-theoretical methods | 2 | 2 |  | |  | 8 | 10 |
| 2 | Section 2. Theory of phase transitions and critical phenomena |  |  |  | |  | 8 | 8 |
| 3 | Section 3. Elements of quantum statistical mechanics |  |  |  | |  | 12 | 12 |
| 4 | Section 4. Multielectron atoms in crystals |  |  |  | |  | 12 | 12 |
| 5 | Section 5. Electronic theory of metals |  |  |  | |  | 10 | 10 |
| б | Section 6. Methods of the band theory of crystals |  |  |  | |  | 8 | 8 |
| 7 | Section 7. Vibrations of lattices, phonons | 2 | 2 |  | |  | 10 | 10 |
| 8 | Section 8. Theory of superconductivity |  |  |  | |  | 10 | 10 |
| 9 | Section 9. Selected topics in the theory of low-dimensional systems |  |  |  | |  | 10 | 10 |
| 10 | Section 10. Elements of the theory of disordered systems |  |  |  | |  | 8 | 8 |
| 11 | Section 11. Standard models and methods of the theory of strongly correlated systems | 2 | 2 |  | |  | 8 | 10 |
| Discipline, total | | | **4** | **4** | |  |  | **104** | **108** |

**3.3. Self-guided work of post-graduate students**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Sections and topics of the work programme for independent study** | | **List of tasks for the self-guided work (research papers, reports, translations, calculations, experiment planning etc.)** | | **Work input** | | | |
| Hour | | Credit | |
| Section 1. Group-theoretical methods | | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 8 | |  | |
| Section 2. Theory of phase transitions and critical phenomena | | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 8 | |  | |
| Section 3. Elements of the quantum statistical mechanics | | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 12 | |  | |
| Section 4. Multielectron atoms in crystals | | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 12 | |  | |
| Section 5. Electronic theory of metals | | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 10 | |  | |
| Section 6. Methods of the band theory of crystals | | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 8 | |  | |
| Section 7. Lattice vibrations, phonons | | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 10 | |  | |
| Section 8. Теория сверхпроводимости | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 10 | |  | |
| Section 9. Selected problems in the theory of low-dimensional systems | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 10 | |  | |
| Section 10. Elements of the theory of disordered systems | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 8 | |  | |
| Section 11. Standard models and methods of the theory of strongly correlated systems | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 8 | |  | |
| **TOTAL** | | | **104** | |  | |

**4. DISCIPLINE LEARNING OUTCOME REQUIREMENTS**

An objective assessment of the level of compliance of the learning outcomes with the educational programme learning requirements is secured by a set of developed criteria (indicators) for assessing the knowledge acquisition, skills development and experience in performing the professional tasks.

|  |  |  |  |
| --- | --- | --- | --- |
| Competence components | Features of the level of mastering competence components | | |
| threshold level | higher level | high level |
| Knowledge | A post-graduate student demonstrates the acquaintance knowledge, copy knowledge, i.e. recognises objects, phenomena and concepts, finds some differences in them, shows the knowledge of the sources of information, can independently carry out reproductive actions on knowledge by self-reproduction and application of the information. | A post-graduate student demonstrates the analytical knowledge, i.e. confidently reproduces and understands the acquired knowledge, assigns them to one or another classification group, independently arranges them, establishes interrelations between them and effectively applies them in familiar situations. | A post-graduate student can independently obtain new knowledge from the surrounding world and creatively use it to make decisions in new and unusual situations. |
| Skills | A post-graduate student is capable of correctly performing the prescribed actions following the instructions and/or an algorithm in a known situation, independently performing actions to address typical issues that require a choice from among the known methods, in predictably changing situations | A post-graduate student is capable of independently performing the actions (techniques, operations) to solve non-standard problems that require selection based on a combination of known methods, in an unpredictably changing situation | A post-graduate student is capable of independently performing the actions associated with solving research problems, demonstrates the creative use of skills (technologies) |
| Personal qualities | A post-graduate student has a low learning motivation, shows an indifferent, irresponsible attitude to studying and/or the assigned task. | A post-graduate student has a pronounced learning motivation and demonstrates a positive attitude towards learning and future activities, and is active. | A post-graduate student has a developed motivation for training and work, shows perseverance and enthusiasm, hard work, independence and creativity. |

**5. APPRAISAL TOOLS TO ENSURE THAT THE ACADEMIC PROGRESS CAN BE REGULARLY MONITORED AND INTERMEDIATE ATTESTATION CONDUCTED**

**The list of test questions (the verifiable competences Universal Competence-1, 5, Professional Competence-1,2)**

1. **Group-theoretical methods.** Symmetry of quantum systems. Wigner’s theorem, symmetry classification of quantum states. Irreducible tensors. Wigner-Eckart theorem.
2. **Theory of phase transitions and critical phenomena.** The theory of structural phase transitions. Unstiffened mode. Metal-insulator phase transition. The theory of magnetic phase transitions. Orientational phase transitions in magnets. The theory of superconducting phase transition. Features of phase transitions in low-temperature and high-temperature superconductors. Features of phase transitions in low-dimensional systems. The Berezinskii-Kosterlitz-Thouless crossover. Peierls structure transition in quasi-one-dimensional electron systems. Critical points. Quantum phase transitions. The percolation theory.
3. **Elements of quantum statistical mechanics**. Quantum field theory methods of at T=0. Diagram technique at finite temperatures. Two-time Green’s functions. The interacting bosons.
4. **Multielectron atoms in crystals.** Classification of the states of a free atom. The crystal field (CF) theory. Multielectron configurations in the scheme of a strong cubic CF. High- and low-spin states of ions with an unfilled 3d shell. The average CF scheme. Crystal 28+1G terms. The weak CF scheme. Stevens’ operator-equivalent method. Interaction of atoms in crystals. Exchange and exchange-relativistic interactions. Spin models of Heisenberg, Ising, Dzyaloshinskii-Moriya. Non-Heisenberg spin Hamiltonians.
5. **Electronic theory of metals.** Oscillation of magnetic susceptibility. Effects of Einstein - de Haas and Shubnikov. Cyclotron resonance. The classical and quantum Hall effects. Fundamentals of the Fermi-liquid theory.
6. **Methods of the band theory of crystals.** Methods for calculating the band structure and the augmented plane wave method. The density functional theory (DFT). The approximations of LDA, LSDA, LDA+U. The dynamic mean field theory.
7. **Lattice vibrations, phonons.** Boltzmann kinetic equation for the gas of phonons. Normal processes and carry-over processes. Phonon gas in an ideal dielectric. Second sound. Quantum crystals. Vacansions. Primesons. The shell model of a crystal.
8. **Superconductivity theory.** The BCS theory or Bardeen–Cooper–Schrieffer theory. The Bogolyubov’s u-v transformation. The Gor’kov equations. The Meissner effect. The basic mechanisms of high-temperature superconductivity.
9. **Selected topics of the theory of low-dimensional systems.** Two-dimensional electronic systems. Wigner crystallisation. Two-dimensional system topology. Spin 2D models. Topological defects. Whirlwinds, skyrmions. The Berezinskii-Kosterlitz-Thouless Theory. 1D and 2D Ising model. Quantum magnets. Magnetic frustration. Incompatible structures.
10. **Elements of the theory of disordered systems.** Basic ideas about Anderson localisation, the scaling theory. The method of replicas and elementary representations of spin glasses. Elementary excitations in the disordered media. Electrons in disordered systems. Phonons in disordered systems. Excitons in disordered systems. Spin glasses. The Edwards-Anderson Model, Parnsey’s Theory.
11. **Standard models and methods of the theory of strongly-correlated systems.** s-d model of Shubin-Vonsovsky. Bogolyubov-Levin model. Anderson model. The Hubbard model. Approximations of the mean field (+RPA). The Hartree-Fock approximation. Solution of the simplest realisations of the Anderson and Hubbard models in the Hartree-Fock approximation. The dynamic mean field theory.

**References**

1. P.A. Lee, T.V. Ramakrishnan. Disordered Electronic Systems. Rev.Mod.Phys. 57, No.2, 287 (1985).
2. Handbook of Magnetism and advanced magnetic materials, Volume I: Fundamentals and Theory, Eds. H. Kronmueller and S. Parkin, Wiley, 2007. 700 p.
3. R.D. Mattuck. D. Johansson. AdvJPhys. 17, 509 (1968).
4. A.S. Moskvin, Spin and Pseudospin Models: Hamiltonians, Topological Excitations, The Physics of Metals and Metallography, Vol. 95, Suppl. 1, 2003, p. 41.

**Electronic educational resources**

* Zonal Scientific Library http://library.urfu.ru/
* Library catalogues http://library.urfu.ru/about/department/cataiog/rescatalog/
* Electronic catalogue http://iibrary.urfix.ru/resources/ec/
* Resources http://library.urfo.ru/resources
* Search http://library.urfu.ru/search

**Databases, information and reference systems and search systems**

* Electronic resources ScienceDirect: http: // www. sciencedirect. com
* Electronic Resources Web of Science: http://apps.weboflaiowiedge.com
* Electronic Resources ScienceDirect; http://vww.scifinder.com
* Electronic Resources Web of Science: http://reaxys.org