**CONTEMPORARY ISSUES FACING CONDENSED MATTER 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/  01.04.07 - condensed matter physics | 30 July 2014  With amendments dated 30 April 2015 | 867  Amendments  464 |

**1.1. Objectives of the discipline**

The objective of the Contemporary Issues Facing Condensed Matter 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 the condensed matter physics.

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

The Contemporary Issues Facing Condensed Matter 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 feel at home in 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 Issues Facing Condensed Matter 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. Electrical, thermal, optical and magnetic properties of condensed systems | 30 |  |
| 2 | Section 2. Nanotechnologies and physics of nanostructures  Topic 1.1 Measurement methods  Topic 1.2 Properties of individual nanoparticles  Topic 1.3 Ferromagnetism in nanostructures  Topic 1.4 Physical properties of nanomaterials | 26 |  |
| 3 | Section 3. Phase transitions and metastable states in solid bodies | 20 |  |
| 4 | Section 4. Materials for recording information | 16 |  |
| 5 | Section 5. Materials for biomedical applications | 16 |  |
|  | **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. Electrical, thermal, optical and magnetic properties of condensed systems | 2 | 2 |  | |  | 28 | 30 |
| 2 | Section 2. Nanotechnologies and physics of nanostructures | 2 | 2 |  | |  | 24 | 26 |
| 3 | Section 3. Phase transitions and metastable states in solids |  |  |  | |  | 20 | 20 |
| 4 | Section 4. Materials for recording information |  |  |  | |  | 16 | 16 |
| 5 | Section 5. Materials for biomedical applications |  |  |  | |  | 16 | 16 |
| 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. Electrical, thermal, optical and magnetic properties of condensed systems | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 28 | |  | |
| Section 2. Nanotechnologies and physics of nanostructures | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 24 | |  | |
| Section 3. Phase transitions and metastable states in solids | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 20 | |  | |
| Section 4. Materials for recording information | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 16 | |  | |
| Section 5. Materials for biomedical applications | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | | 16 | |  | |
| **TOTAL** | | **104** | |  | |

**4. DISCIPLINE LEARNING OUTCOME REQUIREMENTS**

An objective assessment of the level of compliance of the learning outcomes with the principal 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. The band spectrum. Quasimomentum, Brillouin zone. Bloch’s theorem. The dispersion law and the effective mass.
2. Methods for calculating the band spectrum of the pseudopotential method, **k-p** method. The effective mass tensor, the role of symmetric points in the Brillouin zone.
3. The effective mass method. ‘Curvature’ of zones in an external field. Dynamics of an electron in the case of a homogeneous electric field. Solving the hydrogen-like impurity problem.
4. Quasiparticles. Determination, introduction of quasiparticles by the example of an ideal Fermi gas. The Fermi surface. The total number of states in the Brillouin zone. Distribution functions of quasiparticles and particles, chemical potential. Electrons and holes in semiconductors,
5. Quasiparticles in the ideal Bose gas. Distribution functions and chemical potential. Bose condensation. Condensation temperature.
6. Oscillations of the crystal lattice. Dynamic equations, properties of the strength function. The dispersion law. Acoustic and optical oscillations. Transition to a quantum description. Phonons, distribution function. Phonon heat capacity.
7. Motion of electrons in a crystal in an external magnetic field. Trajectories and cyclotron mass. Quantum oscillation phenomena, The de Haas–van Alphen effect and the Shubnikov–de Haas effect. The period of quantum oscillations along the inverse field. Motion of the chemical potential in a magnetic field. Spin splitting. Amplitude of oscillations. Lifshitz-Kosevich-formula, the Dingle temperature. The use of quantum-mechanical oscillationeffects to study the Fermi surface.
8. Drude model, conductivity, Hall effect, magnetoresistance and cyclotron resonance.
9. Kinetic Boltzmann equation. Expression for current and energy flow. The Liouville’s theorem. Approximation of the relaxation time. The relaxation time for the main scattering mechanisms in solids (impurity ions, lattice vibrations, vacancies and point defects, dislocations, crystallite boundaries, electron-electron scattering).
10. Calculation of conductivity using the Boltzmann kinetic equation, Comparison with the Drude model.
11. The percolation theory. The problem of knots on ordered lattices. Clusters. Threshold of flowing. Problems on finite lattices. Problems on infinite lattices.
12. Kinetic properties of heterogeneous media. Conductivity for the case of a small concentration of inclusions. Metallic inclusions in the dielectric matrix. Ideally conducting (superconducting) inclusions in a dielectric matrix. The effect of the shape of inclusions. The critical behaviour of conductivity in the vicinity of the percolation threshold for metallic and superconducting inclusions. Interpolation formulas.
13. Statement of the problem of conductivity concerning the localised states. Hopping conductivity. Miller-Abrahams resistance grid. Solution of the problem of hopping conductivity according to Mott. Conductivity on the direct and alternating currents. Optimal hops.
14. Metal-insulator transition. The random potential, the Fermi-glass mobility threshold. The localised and delocalised states. Anderson’s theorem, Anderson and Mott models. Metal-insulator transition in a doped semiconductor. Mott criteria.
15. Scaling. The problem of describing the metal-insulator transition, the mobility edge as a singular point.
16. Metal-insulator transition in Fermi-glass by Mott. Minimum metallic conductivity. Analysis of experimental data from the point of view of various models, i.e. the Mott model, scaling and quasiclassical percolation theory.
17. Magnetoresistance. Magnetoresistance coefficient. The case of weak and strong fields. Saturation of magnetoresistance. The role of the Hall field. Magnetoresistance in a sample of finite and infinite dimensions. The negative magnetoresistance in the theory of quantum corrections.
18. Features of the structural properties of nanomaterials. Nano-scale in the ‘traditional’ objects of physics of the condensed state of matter (examples). Atomic structures and types of coupling in nanomaterials.
19. The influence of size effects and fluctuations on the mechanical properties of nanoobjects. The strength of nanomaterials (for example, carbon nanotubes).
20. Features of the thermodynamic properties of nanosystems. The specific heat capacity of nano-crystalline objects. The influence of size on the melting temperature of nanoclusters (by the example of gold).
21. Optical conductivity of metallic nanoparticles. Plasma resonance.
22. Transition temperature, coherence length, and penetration depth of the magnetic field in nanostructured superconductors. Vortex lattice in superconductors.
23. The influence of size effects on the band spectrum of semiconductors. Quantum wells, wires and points. Infrared detectors and lasers on quantum dots. One-electron tunnelling through a metallic nanocluster. Coulomb blockade and one-electron transistors. Granulated medium. Quantum Hall effect. The electronic transport in graphene.
24. The influence of size on the magnetic properties of particles. Superparamagnetism. The magnetisation of single-domain particles, the giant and colossal magnetoresistance. Magnetic eddies. Quantum spin chains.
25. Exciton and polariton states in nanomaterials. Photonic crystals.
26. Physical media for quantum computations, i.e. Rydberg atoms, superconductors, optical states, individual impurity atoms in semiconductors and quantum wells. The computer elements, such as registers, quantum wires, converters.
27. Magnetic media for recording information.

**Electronic educational resources**

Zonal Scientific Library http://library.urfu.ru/

Catalogues of the library http://library.urfu.ru/abourdepartment/catalog/rescatalog/

Electronic catalog http://library.urfu.ru/resources/ec/

Resources http://library.urfu.ru/resourees 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.webolknowledse.com

Electronic resources ScienceDirect: http://www.scifmder.com

Electronic resources Web of Science: http://reaxvs.org