**MODERN PROBLEMS OF MAGNETISM**

**1. GENERAL CHARACTERISTICS OF DISCIPLINE**

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

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| --- | --- | --- | --- |
| Code of field  of study | Name of field of study/specialisation | Details of the order of the Ministry of Education and Science of the Russian Federation on approval and commissioning of the Federal State Standard of Higher Education | |
| Date | Number of order |
| 03.06.01 | Physics and astronomy/  01.04.11 - physics of magnetic phenomena 01.04.02 - theoretical physics | 30 July 2014 With changes dated 30 April 2015 | 867  Amendments 464 |

**1.1. Objectives of the discipline**

The discipline Modern Problems of Magnetism is aimed at acquiring the basic professional competencies during an in-depth study of the problems and issues facing researchers at the present time in the field of magnetism and related phenomena.

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

The discipline Modern Problems of Physics of Magnetism refers to the section of the database of the variable part of the basic educational programme of the post-graduate course and is aimed at preparing for passing qualifying examinations for the Ph.D. degree.

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

**Universal Competencies:**

the ability to critically analyse and evaluate current scientific achievements, generate new ideas in solving research and practical problems, including in interdisciplinary 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 to solve research problems in areas corresponding to the chosen area of study, theoretical physics, condensed matter physics, physics of magnetic phenomena, thermophysics and theoretical heat engineering (Professional Competence-1);

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

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **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** |
| Modern Problems of Physics of Magnetism | 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 | **Magnetism of the living matter.** The history of the discovery and use of natural magnetic materials. Classification of biocomponents, unicellular and multicellular living systems. Dimensional scale of biological objects and biocomponent. | 8 |  |
| 2 | **Environment.** Physical environmental factors influencing the life of organisms. Geomagnetism. Hemoglobin and myoglobin. | 8 |  |
| 3 | **Biomembranes.** Molecular and ionic interactions as a basis for the formation of biological structures. Structure and functions of biomembranes. Biomembrane as a selective barrier. Transport properties of biomembranes. A brief overview of the processes taking place on the surface of biomembranes. Organic ionic radicals. | 8 |  |
| 4 | **Electromagnetic fields and biological objects.** Electromagnetic fields surrounded by human beings. The biological effects of electromagnetic fields. An electrocardiogram and a magnetocardiogram. Electroencephalogram and magnetic-encephalogram. | 8 |  |
| 5 | **Principles of constructing magnetic biosensors.** Classification of the existing types of magnetic biosensors. Magnetic markers. The main requirements for magnetic markers for bio-detection. The problem of compatibility of several magnetic materials in one device. | 8 |  |
| 6 | **Examples of magnetic biosensors.** Magnetic biosensors operated on the principle of detecting superparamagnetic markers. Bio ‘chips’. Implanted magnetic sensors and sensors for the analysis of independently functioning living systems. Magnetic biosensors for non-marking detection. | 14 |  |
| 7 | **Neutronography of magnetic substances.** Properties of the neutron. The reaction of fission of uranium. Reactors and neutron sources. Potential and resonant scattering. Coherent and incoherent neutron scattering. Scattering on a bound nucleus. Fermi pseudopotential. Cross-section for neutron scattering by a crystal. Nuclear neutron scattering by crystals. Expression for the intensity of the nuclear reflex. Structural factor. Geometric factor of integrality. Repeatability multiplier. The correction for absorption. Thermal factor. Primary and secondary extinction. Methods for investigating the scattering of neutrons by mono- and polycrystals. | 8 |  |
| 8 | **Magnetic neutron scattering.** Amplitude of magnetic neutron scattering by an electron. Born approximation. Magnetic form factor. Cross-section of magnetic scattering for unpolarised neutrons. Classification of magnetic structures (commensurable and incommensurable magnetic structures, a ferromagnet, an anti-ferromagnet, a ferrimagnet, helicoidal magnetic structures, a spheromagnet, an asperromagetik, a spectromagnet). Magnetic scattering of neutrons by crystals. Coherent scattering by a ferromagnetic structure. Coherent scattering by an antiferromagnetic structure. Wave vector of the magnetic structure. The star of the wave vector. Wave vector group. Cross-section of magnetic scattering on incommensurate structures (simple and elliptical spiral, longitudinal and transverse spin wave). | 8 |  |
| 9 | **Neuronographic measurement equipment and devices**. Diagram of a neutron diffractometer with a constant neutron wavelength. Neutron conductor. Monochromator (crystal-monochromator, focusing monochromator, neutron guide-monochromator). Collimator. Goniometric device for the sample. Cryostat. High temperature attachment. Magnetic system. Pressure cell. Neutron detector (multidetector, position-sensitive detector). The neutron diffractometer scheme using the time-of-flight method. | 8 |  |
| 10 | **Calculation of neutron diffraction patterns.** Manual calculation of neutronograms of simple magnets. Intensity of the magnetic reflex. Dependence of the intensity of magnetic scattering of neutrons on the direction of the momentum in the crystal. Manual calculation of neutron diffraction patterns of the collinear ferro- and antiferromagnets. Application of the Fullprof programme for the calculation of neutronograms of magnets, Programme features. Rietveld refinement of structural parameters. Correspondence factor. Function that describes the profile of the reflex. The programme files. Preparing the file.pcr. Matrices of transformations for rotational elements of cubic and hexagonal groups. Accompanying translations. The source file is the file.dat. Calculation of the neutronogram of iron. | 8 |  |
| 11 | **Symmetry analysis of magnetic structures.** Irreducible representations of space groups. Reducible representations of space group on the basis of localiыed atomic functions. Permutational, mechanical and magnetic representations. Basis functions of еру irreducible representations of space groups. Scalar, vector and pseudovector bases. The concept of an irreducible representation. Application of the Basireps programme for the symmetry analysis of magnetic structures. Calculation of irreducible representations of ‘small groups’. Calculation of the basic functions of irreducible representations of polar and axial vectors. Preparing the input file. Run the programme. Calculation results. | 8 |  |
| 12 | **Examples of research carried out using the magnetic neutron diffraction analysis.** Determination of the magnetic structure of manganite LaMnОз. Calculation of the intensities of nuclear reflexes. Application of temperature. Application of an external magnetic field. The use of polarised neutrons. Refinement of the magnetic structure of a magnet such as a ‘simple spiral’. Refinement of the parameters of the crystalline and magnetic structures of the intermetallic compound YMn6Sn6. Establishment of magnetic structures, determination of temperature dependences of magnetisation in multisublattice magnetic substances. Research into the magnetic phase transitions (transitions of the order-disorder type, order-order order, spin-reorientation transitions). | 14 |  |
|  | **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 | Magnetism of living matter | 2 | 2 |  | |  | 6 | 6 |
| 2 | Environment |  |  |  | |  | 8 | 8 |
| 3 | Biomembranes |  |  |  | |  | 8 | 8 |
| 4 | Electromagnetic fields and biological objects |  |  |  | |  | 8 | 8 |
| 5 | Principles of constructing magnetic biosensors |  |  |  | |  | 8 | 8 |
| б | Examples of magnetic biosensors |  |  |  | |  | 14 | 14 |
| 7 | Neutronography of magnetic substances | 2 | 2 |  | |  | 6 | 6 |
| 8 | Magnetic neutron scattering |  |  |  | |  | 8 | 8 |
| 9 | Neuronographic measurement equipment and devices |  |  |  | |  | 8 | 8 |
| 10 | Calculation of neutron diffraction patterns |  |  |  | |  | В | 8 |
| 11 | Symmetry analysis of magnetic structures |  |  |  | |  | 8 | 8 |
| 12 | Examples of research carried out using the magnetic neutron diffraction analysis |  |  |  | |  | 14 | 14 |
| Discipline, total | | | **4** | **4** | |  |  | **104** | **108** |

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

|  |  |  |  |
| --- | --- | --- | --- |
| Sections and subjects of the self-guided work programme | List of self-guided work assignments (research papers, reports, translations, calculations, experiment planning, etc.) | **Work input** | |
| **Hours** | **Hours** |
| **Magnetism of the living matter.** The history of the discovery and use of natural magnetic materials. Classification of bio-components, unicellular and multicellular living systems. | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | б |  |
| **Environment.** Physical environmental factors influencing the life of organisms. Geomagnetism. Hemoglobin and myoglobin. | Analysis of abstract journals and electronic sources taking into account the content of the discipline (report preparation). | 8 |  |
| **Biomembranes.** Molecular and ionic interactions as a basis for the formation of biological structures. Structure and functions of biomembranes. Biomembrane as a selective barrier. Transport properties of biomembranes. A brief overview of the processes taking place on the surface of biomembranes. Organic ionic radicals. | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | 8 |  |
| **Electromagnetic fields and biological objects.** Electromagnetic fields surrounded by human beings. Biological effects of electromagnetic fields. Electrocardiogram and magnetocardiogram. Electroencephalogram and magneto-endophalogram. | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | 8 |  |
| **Principles of constructing magnetic biosensors.** Classification of the existing types of magnetic biosensors. Magnetic markers. The basic requirements for magnetic markers for bio-detection. The problem of compatibility of several magnetic materials in one device. | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | 8 |  |
| **Examples of magnetic biosensors.**  Magnetic biosensors operated according to the principle of detecting superparamagnetic markers. Bio ‘chips’.  Implanted magnetic sensors and sensors for the analysis of independently functioning living systems. Magnetic biosensors for label-free detection. | Working with the recommended literature, analysis of abstract journals and electronic sources, taking into account the content of the discipline (writing compendia). | 14 |  |
| **Neutronography of magnetic substances.** Properties of the neutron. The reaction of the fission of uranium. Reactors and neutron sources. Potential and resonant scattering. Coherent and incoherent neutron scattering. Scattering on a bound nucleus, Fermi pseudopotential. Cross-section for neutron scattering by a crystal. Nuclear neutron scattering by crystals. Expression for the intensity of the nuclear reflex. Structural factor. Geometric factor of integration, Repeatability factor. Absorption correction. Thermal factor. Primary and secondary extinction. | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | 6 |  |
| **Magnetic neutron scattering.** The amplitude of magnetic neutron scattering on an electron. Born approximation. Magnetic form factor. Cross-section of magnetic scattering for non-implanted neutrons. The classification of magnetic structures (commensurable and incommensurable magnetic structures, a ferromagnet, an antiferromagnet, a ferrimagnet, helicoidal magnetic structures, a magnet, an asperromagnet, a spectromagnet). Magnetic scattering of neutrons by crystals. Coherent scattering by a ferromagnetic structure. Coherent scattering by an antiferromagnetic structure. Wave vector of the magnetic structure. The star of the wave vector. Wave vector group. Cross-section of magnetic scattering on incommensurate structures (simple and elliptical spiral, the longitudinal and transverse spin wave). | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | 8 |  |
| **Neuronographic measurement equipment and devices.** The scheme of a neutron diffractometer with a constant neutron wavelength. Neutron conductor. Monochromator (crystal monochromator, focusing monochromator, neutron guide monochromator). Collimator. Goniometer device for the sample. Cryostat. High temperature attachment. Magnetic system. Pressure cell. Neutron detector (multidetector, position-sensitive detector). The scheme of a neutron diffractometer using the time-of-flight method. | Working with recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). |  |  |
| **Calculation of neutron diffraction patterns.** Manual calculation of the neutronograms of simple magnets. Intensity of the magnetic reflex. Dependence of the intensity of magnetic scattering of neutrons on the direction of the momentum in the crystal. Manual calculation of neutron diffraction patterns of the collinear ferro- and antiferromagnets. Application of the Fullprof programme for the calculation of neutronograms of magnets. Features of the programme. Rietveld structural parameters refinement. Correspondence factor. Function that describes the profile of the reflex. The programme files. Preparing the file. Matrices of transformations for the rotational elements of cubic and hexagonal groups. Accompanying broadcasts. The source file is the file.dat. Calculation of the neutronogram of iron. | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | 8 |  |
| **Symmetry analysis of magnetic structures.** Irreducible representations of space groups. Reducible representations of the space group on the basis of localised atomic functions. Permutational, mechanical and magnetic representations. Basis functions of irreducible representations of space groups. Scalar, vector and pseudovector bases. The concept of an irreducible representation. Application of the Basireps programme for the symmetry analysis of magnetic structures. Calculation of irreducible representations of ‘small groups’. Calculation of the basis functions of irreducible representations of polar and axialvectors. Preparing the input file. Run the programme. Calculation results. | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing abstracts). | 8 |  |
| **Examples of research carried out using the magnetic neutron diffraction analysis.** Determination of the magnetic structure of manganite LaMnO3. Calculation of the intensities of nuclear reflexes. Application of temperature. Application of an external magnetic field. The use of polarised neutrons. Refinement of the magnetic structure of a magnet such as a ‘simple spiral’. Refinement of the parameters of the crystalline and magnetic structures of the inter-metallic compound YMn6Sn6. Establishment of magnetic structures, determination of temperature dependences of magnetisation in multi-sub-lattice magnetic substances. Investigation of magnetic phase transitions (transitions of the order-disorder type, order-order order, spin-reorientation transitions). | Working with the recommended literature, analysis of abstract journals and electronic sources taking into account the content of the discipline (writing compendia). | 14 |  |
| **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 (technology) |
| 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. Natural magnetic materials. Classification of biocomponents, unicellular and multicellular living systems. Dimensional scale of biological objects and biocomponent.
2. Physical factors of the environment that have an impact on the vital activities of organisms. Geomagnetism. Hemoglobin and myoglobin.
3. Molecular and ionic interactions as a basis for the formation of biological structures. The structure, functions and properties of biomembranes. Biomembrane as a selective barrier. Organic ionic radicals.
4. Electromagnetic fields surrounded by human beings. The biological effects of electromagnetic fields. An electrocardiogram and a magnetocardiogram. An electroencephalogram and a magnetic encephalogram.
5. Classification of the existing types of magnetic biosensors. Magnetic markers. The basic requirements for magnetic markers for bio-detection. The problem of compatibility of several magnetic materials in one device.
6. Magnetic biosensors operated on the supernaramagnetic marker detection principle. Bio’chips’. Implanted magnetic sensors and the sensors for the analysis of independently functioning living systems. Magnetic biosensors for non-marking detection.
7. Fundamentals of neutron diffraction. Methods for investigating neutron scattering by mono- and polycrystals.
8. Amplitude of magnetic scattering of a neutron on an electron. Born approximation. Magnetic form factor. Cross-section of magnetic scattering for unpolarised neutrons.
9. Classification of magnetic structures (commensurable and incommensurable magnetic structures, ferromagnet, antiferromagnet, ferrimagnet, helicoidal magnetic structures, spheromagnet, asperromagnet, spermagnet).
10. Magnetic scattering of neutrons by crystals.
11. Coherent scattering by a ferromagnetic structure. Coherent scattering by an antiferromagnetic structure.
12. Wave vector of the magnetic structure. The wave vector star. The wave vector group.
13. Cross-section of magnetic scattering on incommensurable structures (simple and elliptical spirals, a longitudinal spin wave and a transverse spin wave).
14. Diagram of a neutron diffractometer with a constant neutron wavelength. Neutron-water. Monochromator (a crystal monochromator, a focusing monochromator, a neutron-water-monochromator). Collimator. Goniometer device for a sample. Cryostat. High-temperature attachment. Magnetic system. Pressure cell. Neutron detector (multidetector, position-sensitive detector). The neutron diffractometer scheme using the time-of-flight method.
15. Manual calculation of neutronograms of simple magnets. Intensity of the magnetic reflex. Dependence of the intensity of magnetic scattering of neutrons on the direction of the momentum in the crystal.
16. Manual calculation of neutron diffraction patterns of collinear ferro- and antiferromagnets.
17. Application of the Fullprof programme for the calculation of neutronograms of magnets. The programme features. Rietveld method of refinement of structural parameters. Correspondence factor. Function that describes the profile of the reflex.
18. Irreducible representations of space groups. Reducible representations of a space group on the basis of the localised atomic functions. Permutational, mechanical and magnetic representations. Basis functions of irreducible representations of space groups. Scalar, vector and pseudovector bases. The concept of an irreducible representation.
19. The use of the Basireps programme for the symmetry analysis of magnetic structures. Calculation of the irreducible representations of ‘small groups’. Calculation of the basis functions of the irreducible representations of polar and axial vectors.
20. Establishment of magnetic structures, determination of temperature dependences of magnetisation in multisublattice magnetic structures by using the magnetic neutron diffraction method.
21. Research into magnetic phase transitions (transitions of the order-disorder type, order-order, spin-reorientation transitions) by using the magnetic neutron diffraction method.

**References**

1. Iron, Nature's universal element, E.V. Mielczarec, S.B. McGrayne, Rutgers University Press, 2000.

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1. Bazylinski D.A., Frankel R.B. Magnetosome formation in prokaryotes, Nature Reviews. Microbiology, 2, 2004, 217-230.
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3. Giant Magnetoimpedance for Biosensing, G. V, Kurlyandskaya, M, A, Cerdeira, Encyclopedia of Nanoscience and Nanotechnology Edited by H. S. Nalwa, Volume 15: Pages (1-17), 2011.
4. Glaser R, Biophysics, Springer, 1999.
5. Megens M„ Prins М., Magnetic biochips: a new option for sensitive diagnostics, J. Magn. Magn. Mater. 293 (2005) 702-708.
6. Biomagnetism and Magnetic Biosystems based on molecular recognition process, Editors J. Anthony C. Bland, Adrian lonescu, AIP conference Proceedings, 1025, New York, 2008.
7. Kurlyandskaya G.V., Levit V.I., Magnetic Dynabeads detection by sensitive element based on giant magnetoimpedance, Bios. Bioelectr. 20 (2005)1611-1616.

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

* ScienceDirect Electronic Resources: http://www.sciencedifect.com:
* WeboiScience Electronic resources: http://apps.webofknowledae.com:
* ScienceDirect Electronic Resources: http://www.scifinder.com
* WebofScience Electronic resources: http://reaxvs.org