Magnetism and Magnetic Materials

Educational subject description sheet

Basic information

Study programme Fizyka **Speciality** INFORMACJA KWANTOWA I SPINTRONIKA **Organizational unit** Faculty of Physics **Study level** Second-cycle programme **Study form** Full-time **Education profile** General academic	**Didactic cycle** 2023/24 **Subject code** 04FIZIKSS.21S.04362.23 **Lecture languages** English **Course type** Obligatory **Block** specialty subjects

Subject coordinator	Maciej Krawczyk
Lecturer	Maciej Krawczyk, Paweł Gruszecki

Period	**Activities and hours**	**Number of ECTS points**
Semester 1	• Lecture: 30, Exam • Classes: 30, Graded credit • Laboratories: 30, Graded credit	7

Goals

Code	Goal
C1	Introducing students to the physics of magnetism, magnetic materials and magnetization dynamics.
C2	Making students aware of the problems with the current research topics and open questions in the physics of magnetism.
C3	Familiarize students with current applications and prospects for future magnetic materials and magnonics development.
C4	Developing the ability to read and understand scientific papers on the physics of magnetism, draw conclusions, formulate research problems and analyze potential ways to solve them.
C5	Acquainting knowledge about the basic models in the physics of magnetism and methods of solving them. Familiarization with the selected methods of solving selected tasks related to magnetization static texture, magnetization, and spin-wave dynamics.
C6	Familiarization with micromagnetic simulations and using them to solve selected problems in the physics of magnetism.

Subject learning outcomes

Code	Outcomes in terms of	Learning outcomes	Examination methods
Knowledge – Student:			
W1	Knows the principles of electromagnetic and magnetostatic effects related to the magnetic field and magnetic materials. Knows the basic equations describing magnetostatic potential and magnetic field distribution.	FIZ_K2_W01	Oral exam, Written colloquium, Project, Report
W2	Knows the main directions of development of research and technologies related to magnetism and their contribution to the generation and saving of electricity.	FIZ_K2_W04, FIZ_K2_W05	Oral exam
W3	Knows the basic principles of experimental methods used to study magnetic materials and the dynamics of magnetization and is able to indicate their limitations.	FIZ_K2_W01, FIZ_K2_W02, FIZ_K2_W04, FIZ_K2_W05	Oral exam, Written colloquium, Project
W4	Knows the selected models used to describe magnetism, magnetization dynamics, and spin-wave dynamics in magnetic materials.	FIZ_K2_W01, FIZ_K2_W02, FIZ_K2_W03	Oral exam, Written colloquium, Project, Report
W5	Knows the different types of magnetic materials, stable magnetization arrangement, magnetization textures that exist in solids, the types of interactions responsible for their stabilization, and the models for describing them.	FIZ_K2_W01, FIZ_K2_W02, FIZ_K2_W03	Oral exam, Written colloquium, Project, Report
W6	Knows selected topics of the current research in magnetism, and can explain their main principles, e.g., artificial spin ice, magnonics, and magnetic cellular quantum automata.	FIZ_K2_W02, FIZ_K2_W03, FIZ_K2_W04, FIZ_K2_W05	Oral exam, Written colloquium, Project
W7	Knows the basics of time and position-dependent signal processing using Fast Fourier Transforms.	FIZ_K2_W01, FIZ_K2_W02, FIZ_K2_W03	Written colloquium, Project
Skills – Student:			

Code	Outcomes in terms of	Learning outcomes	Examination methods
U1	Uses basic theoretical models to qualitatively describe interactions that exist in magnetic materials, can identify different energy terms, and can describe magnetic properties related to these interactions.	FIZ_K2_U01, FIZ_K2_U03	Oral exam, Written colloquium, Project, Report
U2	Can identify the types of interactions responsible for stabilizing different magnetization textures.	FIZ_K2_U01, FIZ_K2_U03	Oral exam, Written colloquium, Project, Report
U3	Demonstrates the ability to read research articles with understanding and the ability to present the outcomes, summary, and the importance of research in writing.	FIZ_K2_U02, FIZ_K2_U03, FIZ_K2_U04, FIZ_K2_U05, FIZ_K2_U07	Oral exam, Project, Report
U4	Can formulate a research problem and indicate the method and basic methodological approach to its solution.	FIZ_K2_U03, FIZ_K2_U05, FIZ_K2_U07	Oral exam, Project, Report
U5	is able to use the Python programming language and jupyter-lab environment for the analysis of scientific data.	FIZ_K2_U01, FIZ_K2_U02	Project

Study content

No.	Course content	Subject learning outcomes	Activities
1.	Overview of magnetism, magnetic materials, and the current topics of research and technology development.	W1, W6	Lecture, Classes
2.	Basic laws of magnetostatics and electrodynamics related to magnetism, magnetic field, magnetostatic potential, magnetic moment, magnetic dipole, magnetization, and magnetic torque. Exemplary applications of permanent magnets and soft magnets	W1, W2, W3, U1, U2	Lecture, Classes, Laboratories
3.	Magnetic materials: paramagnetism, ferromagnetism/antiferromagnetism and diamagnetism. Fundamental concepts of magnetism, the interactions, and complexity.	W2, W6, U2, U3, U4	Lecture, Classes
4.	Remagnetization process in ferromagnetic materials, single-domain grains, hysteresis, complex magnetization textures, open questions, and actual investigations: super-paramagnets and super-ferromagnets, artificial spin-ice systems, frustration, and stability.	W2, W4, W5, W6, U1, U2, U3	Lecture, Classes, Laboratories
5.	Fundamentals: the origin of magnetism in solids, theoretical models and numerical methods used in computations of properties of the magnetic materials, micromagnetic approach.	W2, W4, W5, W6, U2	Lecture, Classes, Laboratories
6.	Magnetic domains: types and interactions determining their stability.	W1, W2, W3, W5, U2	Lecture, Classes, Laboratories
7.	Experimental methods for characterization of magnetic materials, magnetization textures, and magnetization dynamics. Current trends and needs.	W1, W2, W6, U3, U4	Lecture, Classes
8.	Magnetization dynamics, micromagnetism, Landau-Lifshitz equation, damping.	W2, W4, W6, U1, U3	Lecture, Classes, Laboratories

No.	Course content	Subject learning outcomes	Activities
9.	Magnonics, wave phenomena in ferromagnets and antiferromagnets, spin wave dynamics in thin films, characteristic dispersion relationships, detection techniques and possible applications.	W5, W6, U2, U3	Lecture, Classes, Laboratories
10.	Python programming for the analysis of scientific data, Fast Fourier Transformation of signal processing.	W7, U5	Laboratories

Additional information

Activities	Teaching and learning methods and activities
Lecture	Lecture with a multimedia presentation of selected issues, Discussion, Activating method - "brainstorming"
Classes	Solving tasks (e.g. computational, artistic, practical), Classes method, Project method
Laboratories	Case study, Problem-based learning, Solving tasks (e.g. computational, artistic, practical), Research method (scientific inquiry)

Activities	Credit conditions
Lecture	The condition for taking the lecture exam is passing the Classes and Laboratories. The final grade will be based on the average from the report part and the oral exam [(oral exam points + report points)/2], but each part independently has to receive a score larger than 2,0. The report (15 000 – 17 000 chars with spaces) will be based on the research paper(s) on one topic, selected from the provided list of research papers. The points (from 2.0 to 5.0 points) will take into account the quality of the presentation and its style, its logic, the clearness of the problem description, and its consistency. At the oral exam, everyone will receive 3 questions drawn from the knowledge topics (2 questions) and a problem task from the new research (1). The full answer for each question gives from 2 to 5 points (pt), and the final score is an arithmetic average of the obtained points. Very good (bdb; 5,0): (4.5pt - 5.0pt> Good plus (+db; 4,5): (4,0pt - 4.5pt> Good (db; 4,0): (3,5pt – 4,0pt> Satisfactory plus (+dst; 3,5): (3,0pt – 3,5pt> Satisfactory (dst; 3,0): (2,5pt – 3,5pt> Unsatisfactory (ndst; 2,0): less than 2.5pt
Classes	Passing the course requires the completion of two written colloquia and the completion of one or two projects. The projects will be based on the development and class presentation of selected problems based on literature provided by the instructor. The final grade will be the average of the written colloquia and the project/projects grades.
Laboratories	The requirement for successful completion of the course is the completion of all laboratory classes, as well as the execution of an individual project and the presentation of its results. Under the condition of passing all laboratories, the grade is given on the basis of the project.

Literature

Obligatory

1. J. M. D. Coey, “Magnetism and magnetic materials”, (Cambridge University Press, 2009), chapters 1-13.
2. C. Kittel, ”Introduction to the solid state physics”, (PWN, Warszawa 1999 or John Wiley & Sons, Inc., Ed. 8th, 2005); two chapters related to the band structure formation and magnetism.
3. R. P. Cowburn and M. E. Welland, Room Temperature Magnetic Quantum Cellular Automata, Science 287, 1466 (2000); DOI: 10.1126/science.287.5457.1466
4. W. Ketterle and D.E. Pritchard, Trapping and focusing ground state atoms with static fields, Appl. Phys. B 54, 403406 (1992);
5. A. Vansteenkiste, J. Leliaert, M. Dvornik, M. Helsen, F. Garcia-Sanchez, and B. Van Waeyenberge, The design and verification of MuMax3, AIP Advances 4, 107133 (2014);

Optional

1. J. Stoehr, H. C. Siegemann, “Magnetism, from fundamentals to nanoscale dynamics” (Springer, 2006);
2. A. Hubert, R. Schafer, “Magnetic domains, the analysis of magnetic microstructures” (Springer, 2009);
3. Z. Guo, et al., Spintronics for Energy-Efficient Computing: An Overview and Outlook, PROCEEDINGS OF THE IEEE 109, 1398 (2021); DOI: 10.1109/JPROC.2021.3084997
4. N. D. Mermin and H. Wagner, Absence of ferromagnetism or antiferromagnetism in one- or two-dimensional isotropic Heisenberg models, Phys. Rev. Lett. 17, 1133 (1966).

Calculation of ECTS points

Activities	**Activity hours***
Lecture	30
Classes	30
Laboratories	30
Preparation for classes	20
Report preparation	10
Preparation for the exam	15
Preparation of a project	30
Preparation for the assessment	10
Reading the indicated literature	20
Student workload	**Hours** 195
Number of ECTS points	**ECTS** 7

* academic hour = 45 minutes

Efekty uczenia się dla kierunku

Kod	Treść
FIZ_K2_U01	The graduate can use their knowledge to formulate and solve complex and unusual problems in the field of physical sciences; select and apply appropriate methods and tools necessary to solve a given problem (including advanced IT techniques), as well as adapt existing methods and tools or develop completely new ones
FIZ_K2_U02	The graduate can find the necessary information in the professional literature, databases and other sources, in particular in scientific journals basic to physics, and perform critical analysis, synthesis and creative interpretation of the collected information
FIZ_K2_U03	The graduate can formulate and test hypotheses related to simple research problems in physics (plan and perform observations, experiments, theoretical calculations or computer simulations and critically evaluate and discuss the results obtained)
FIZ_K2_U04	The graduate can prepare, for various audiences, oral presentations and written studies presenting specialized topics in the field of physical sciences in a communicative way, as well as debate on such topics
FIZ_K2_U05	The graduate can use English in accordance with the requirements set out for level B2+ of the Common European Framework of Reference for Languages, as well as specialist English terminology in the field of physical sciences
FIZ_K2_U07	The graduate can independently determine the directions of further learning and implement a self-education program, learn throughout lifetime using the available international literature and be able to guide others in this regard
FIZ_K2_W01	The graduate knows and understands in-depth selected facts, phenomena, concepts and theories specific to physics and complex relationships between them (constituting advanced general knowledge in the field of physical sciences and representing both key and other selected issues in the field of advanced detailed knowledge in this discipline)
FIZ_K2_W02	The graduate knows and understands in-depth selected research methods and tools as well as mathematical models used in physics
FIZ_K2_W03	The graduate knows and understands in-depth selected computational methods and information technology tools and techniques used to solve complex problems in physics
FIZ_K2_W04	The graduate knows and understands main development trends in the discipline of physical sciences
FIZ_K2_W05	The graduate knows and understands the role of physical sciences in the context of fundamental dilemmas and challenges of modern civilization