Appendix No. 1.5 to the Resolution No. 7/2023

 of the Rector of the University of Rzeszów

**SYLLABUS**

**regarding the qualification cycle FROM ………TO…..**

**Academic year 2024/2025**

1. Basic Course/Module Information

|  |  |
| --- | --- |
| Course/Module title | *Solid state physics* |
| Course/Module code \* |  |
| Faculty (name of the unit offering the field of study) | *College of Natural Science* |
| Name of the unit running the course | *Institute of Physics* |
| Field of study | Physics |
| Qualification level  | Second-cycle studies |
| Profile | *General academic* |
| Study mode | *Full-time studies* |
| Year and semester of studies | *1st year, summer semester* |
| Course type | *Directional course* |
| Language of instruction | English |
| Coordinator | Dr hab. Małgorzata Sznajder, prof. UR |
| Course instructor | *Dr hab. Małgorzata Sznajder, prof. UR* |

\* - as agreed at the faculty

1.1.Learning format – number of hours and ECTS credits

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Semester(n0.) | Lectures | Classes | Colloquia | Lab classes | Seminars | Practical classes | Internships | others | **ECTS credits**  |
| 1 |  | 30 |  |  |  |  |  |  | 5 |

1.2. Course delivery methods

- conducted in a traditional way

- involving distance education methods and techniques

1.3. Course/Module assessment (exam, pass with a grade, pass without a grade)

pass with a grade

2. Prerequisites

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| Knowledge of the fundamentals of physics (kinematics, mechanics, electromagnetism, optics and the structure of the atom), mathematical analysis (integral and differential calculus). Knowledge of quantum mechanics issues related to solutions of the stationary Schroedinger’s equation for a particle in a potential well, potential barriers, tunneling effect, knowledge of electron spin, Pauli exclusion principle, magnetic moments, perturbation theory for non-degenerate and degenerate cases. |

3. Objectives, Learning Outcomes, Course Content, and Instructional Methods

3.1. Course/Module objectives

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| --- | --- |
| O1 | Acquisition by students of thorough knowledge of the structure and physical properties of solids, in particular metals, semiconductors and magnets. |
| O2 | Provide students with the basic calculation methods of the band structure of solids. |
| O3 | Provide students with the basic methodology of experimental research in solid state physics. |
| O4 | Developing the ability to intuitively understand the discussed physical phenomena and use the correct physical terminology. |
| O5 | Provide students with knowledge enabling conducting scientific research in the field of selected issues of solid state physics. |

3.2. Course/Module Learning Outcomes (to be completed by the coordinator)

|  |  |  |
| --- | --- | --- |
| Learning Outcome | The description of the learning outcome defined for the course/module | Relation to the degree programme outcomes |
| LO\_01 | The student knows and understands in depth issues in the field of physical properties of solids, including metals, semiconductors, magnetics and amorphous bodies, as well as the importance of solid state physics for the progress of exact and natural sciences | K\_W01 |
| LO\_02 | knows and understands the current directions of development and the latest discoveries in the field of experimental methods of manufacturing modern semiconductors, including those working in extreme conditions of high power, frequency and temperature | K\_W06 |
| LO\_03 | knows and understands the fundamental dilemmas of the modern development of physics | K\_W07 |
| LO\_04 | is able to: plan studies of the crystal structure of the material using the X-ray scattering method, transport properties using the Hall method or how to measure the energy bandgap of the material | K\_U01 |
| LO\_05 | is able to critically evaluate the results of experiments, observations and theoretical calculations regarding the band structure of the material, the value of the adsorption energy of the element on the surface of the material, is able to evaluate the experimental temperature dependencies of the basic characteristics of metals and semiconductors and, based on their course, identify the type of material, as well as discuss measurement errors | K\_U02 |
| LO\_06 | is able to present the results of research in the form of report containing a description and justification of the purpose of the work, the adopted methodology, results and their analysis | K\_U04 |
| LO\_07 | is ready to: recognize the limitations of their own knowledge and the need to consult experts in the situation of difficulties with solving of a problem concerning solid state physics | K\_K02 |
| LO\_08 | is ready to: systematically read scientific and popular science journals, basic for solid state physics, in order to broaden and deepen knowledge and develop professional achievements | K\_K06 |

**3.3. Course content (to be completed by the coordinator)**

1. Lectures

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| Content outline |
| 1. **Introduction**. Phases of matter - condensed phase - crystals, amorphous materials, polycrystalline materials, liquid crystals, glasses – recollection and systematization of their basic properties. |
| 2.**Crystallograhy**. Problems of symmetry of crystals, the concept of symmetry group, symmetry class, crystal space group, crystallographic class. Hierarchy of crystallographic systems in terms of symmetry. Selected crystal structures (e.g. wurtzite, perovskite and examples of modern materials crystallizing in these structures). The phenomenon of polytypism on the example of iron and carbon. Miller's indices. Comparison of LEC, Czochralski and Bridgman methods for single crystal growth. |
| 3.**Crystal binding**. Chemical bonds in solids:Ionic, covalent, hydrogen, metallic, van der Waals bonds.4.**Wave diffraction and the reciprocal lattice**. The concept of reciprocal lattice and Brillouin zone. Diffraction of photons, neutrons and electrons on crystals, the mechanism of formation of a diffracted beam on a crystal. Scattered wave amplitude and Fourier analysis. Derivation of the Laue equations using the concept of reciprocal lattice vectors. The diffraction condition formulated for elastic scattering and its equivalence with the Laue condition. Ewald's construction. Reciprocal lattice to sc, bcc, fcc and hexagonal lattices. Structure factor of the fcc and bcc lattices, atomic form factor. Experimental methods. |
| 5. **Dynamics and thermal properties of crystal lattice**. Vibrations and waves in a one-dimensional crystal lattice with one and two atoms in a cell. Dispersion relations: acoustic and optical branches. Group and phase velocities, long-wave approximation. Thermal vibrations of one-dimensional lattice as normal vibrations. Quantization of lattice vibrations. Phonons. Vibrations of atoms in a three-dimensional complex crystal lattice. Thermodynamic functions in a solid. Density of states. Debye model of specific heat. Experiments with inelastic neutron scattering in a crystal, N and U processes.  |
| 6.**Basic approximations in the band theory of solids**. Adiabatic approximation, one-electron approximation. |
| 7. **Electron states in a perfect crystal**. General properties of an electron moving in a periodic crystal potential. Solution of the Schroedinger equation within the free and nearly free electron approximations and graphical interpretation of the solutions. The mechanism of energy band gap formation and the scheme of the band structure in the reduced Brillouin zone. Energy diagrams of a dielectric, conductor, semiconductor and semi-metal. Examples of electronic band structures of selected metals and semiconductors. Bloch's theorem. ***k***-vector as a quantum number, the quasi-momentum of the electron in the crystal. Born–Karman boundary conditions for the electron wave function in a crystal. Quantization of electronic states in the energy band. Motion of electrons under the influence of an external electric field. Effective mass tensor. Density of energy states function. |
| 8. **Free electron Fermi gas**. Degenerate electron gas in metals. Fermi-Dirac distribution function at various temperature conditions. Fermi surface in metals and Harrison constructions. Experimental methods for studying Fermi surfaces: the de Haas-van Alphen effect in Onsager's approach. Landau levels of a free electron in a magnetic field. Low-dimensional structures: nanowires and quantum dots. Graphene, basic properties, production methods, application, Nobel Prize in Physics in 2010. |
| 9. **Electrical conductivity in semiconductors**. Effective mass of charge carriers in semiconductors. Band structures of selected semiconductors. Dispersion laws for charge carriers. Heavy and light holes. Equilibrium concentrations of free charge carriers in intrinsic semiconductors, derivation of the temperature dependences of carrier concentration and Fermi level.Influence of dopants on the electroconductivity of a semiconductor. Semiconductors operating in extreme conditions of high power, temperature and frequency (SiC, AlN, GaN), selected methods of manufacturing semiconductor heterostructures of these materials (MBE, MOCVD). Nitride materials and the 2014 Nobel Prize in Physics. for achievements in the field of their production. |
| 10.**Transpost phenomena in metals and semiconductors**. Shortcomings of Drude's theory of conductivity. Boltzmann equation in the relaxation time approximation – the field and collision terms. Electrical conductivity of non-degenerate semiconductors with a simple band structure. Types of carrier scattering mechanisms and their influence on the relaxation time. Hall effect in semiconductors. Hall constant for two types of majority carriers. Determination of concentration and mobility of carriers. Quantum Hall effect. |
| 11. **Magnetic properties of solids**. Influence of the magnetic field on angular motion of electron. Diamagnetism. Quantum theory of paramagnetism. Magnetic permeability, Curie's law. Atom as a magnetic dipole. Spin. Ferromagnetic, ferri- and antiferromagnetic order. Neel's temperature. Curie point. Magnetic hysteresis. Origin of magnetic domains, coercivity. |
| 12. **Physics of surfaces and interfaces**. Physical and chemical adsorption. Surface reconstruction – project work. |

1. Classes, tutorials/seminars, colloquia, laboratories, practical classes

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| Content outline  |
| The same as above |
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3.4. Methods of Instruction

*A lecture supported by a multimedia presentation.*

*Classes: group work (problem solving, discussion).*

*Project 1 - constructions of Brillouin zones on graph paper for various types of lattices,*

*Project 2 - Ewald constructions*

*Project 3 - determination of the energy gap value of the material based on experimental data,*

*Project 4 - determination of the adsorption energy of an element on the substrate surface based on numerical data.*

4. Assessment techniques and criteria

4.1 Methods of evaluating learning outcomes

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| --- | --- | --- |
| Learning outcome | Methods of assessment of learning outcomes (e.g. test, oral exam, written exam, project, report, observation during classes) | Learning format (lectures, classes,…) |
| LO-01 | observation during classes, solving problems, test, written exam  | L, c |
| LO-o2 | written exam  | L |
| LO\_03 | written exam  | L |
| LO\_04 | written exam  | L |
| LO\_05 | project, observation during classes | C |
| LO\_06 | project, observation during classes | C |
| LO\_07 | observation during classes, solving problems, test, written exam  | L, c |
| LO\_08 | observation during classes, solving problems, test, written exam  | L, c |

4.2 Course assessment criteria

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| --- |
| Passing the subject is obtained on the basis of completed classes, completed project and obtaining a positive grade in the exam. The student must pass Project No. 1 and 2 and any project from Nos. 3 and 4. The final grade for the classes is the arithmetic average of the grades from the two mid-semester tests. The student's activity in class and partial grades are also taken into account. The written exam consists of about 5 issues to be worked out. Each task corresponds to a score of 1 - 6 points. The written part of the exam is passed after the student has scored at least 51% of the maximum number of points. |

5. Total student workload needed to achieve the intended learning outcomes

– number of hours and ECTS credits

|  |  |
| --- | --- |
| Activity | Number of hours |
| Scheduled course contact hours | 30 |
| Other contact hours involving the teacher (consultation hours, examinations) | 5 |
| Non-contact hours - student's own work (preparation for classes or examinations, projects, etc.) | 50 |
| Total number of hours | 85 |
| Total number of ECTS credits | 5 |

\* One ECTS point corresponds to 25-30 hours of total student workload

6. Internships related to the course/module

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| --- | --- |
| Number of hours | *Not applicable* |
| Internship regulations and procedures |  |

7. Instructional materials

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| Compulsory literature:1.Ch.Kittel, introduction to solid state physics, John Wiley & Sons, Ltd, 20052.H. Ibach, H. luth, Solid-state physics, springer 20033.o. madelung introduction to solid-state theory, springer, 1996 |
| Complementary literature: 1.Michael C. Petty “Molecular Electronics From Principles to Practice”, John Wiley & Sons, Ltd, 20082.O. Madelung, “Semiconductors: Data Handbook”, 3rd ed. Edited by O. Madelung, Springer, Berlin 2004 |

Approved by the Head of the Department or an authorised person