



### COURSE UNIT (MODULE) DESCRIPTION

| Course unit (module) title | Code |
|----------------------------|------|
| Solid state physics        |      |

| Lecturer(s)                                    | Department(s) where the course unit (module) is delivered |
|------------------------------------------------|-----------------------------------------------------------|
| Coordinator: prof. assis. Ramūnas Aleksiejūnas | Physics Faculty                                           |
| Other(s): dr. Tadas Malinauskas                |                                                           |

| Study cycle | Type of the course unit (module) |
|-------------|----------------------------------|
| BA          |                                  |

| Mode of delivery | Period when the course unit (module) is delivered | Language(s) of instruction |
|------------------|---------------------------------------------------|----------------------------|
| Lectures         | 3 term, spring                                    | English/Lithuanian         |

| Requirements for students                                                      |                                          |
|--------------------------------------------------------------------------------|------------------------------------------|
| <b>Prerequisites:</b><br>General physics I and II, Higher mathematics I and II | <b>Additional requirements (if any):</b> |

| Course (module) volume in credits | Total student's workload | Contact hours | Self-study hours |
|-----------------------------------|--------------------------|---------------|------------------|
| 10                                | 250                      | 160           | 90               |

| Purpose of the course unit (module): programme competences to be developed                                                                                                                                                                               |
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| A student will acquire knowledge of quantum mechanics at introductory level and knowledge of solid state physics. She will be able to apply them practically. Ability to gather and analyse information from various sources will be developed, as well. |

| Learning outcomes of the course unit (module)                                                                                                                                                                                                                                                                                                                                                                                                                      | Teaching and learning methods                                                                                                                                                                                                                                                                                                                                                               | Assessment methods                                                                                                                                                                                                           |
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| After completing the course, the students will be able to: <ul style="list-style-type: none"> <li>Understand basic concepts and terminology in the fields of quantum mechanics and solid state physics (1.3)</li> <li>Be able to apply theoretical knowledge for solving of problems and analysis of experimental data (1.2, 3.2)</li> <li>Know and be able to use the main characterization techniques for electronic transport characterization (1.1)</li> </ul> | Student-oriented methods: <ul style="list-style-type: none"> <li>Informative (lecture; audiovisual presentation, problem solving explanation, etc.);</li> <li>Interactive (analysis of physical problems and situations in the study groups);</li> <li>Self-study (Textbook reading, searching for information, analysis and presentation of laboratory works, problem solving).</li> </ul> | Oral and written examination. Cumulative assessment: <ul style="list-style-type: none"> <li>Intermediate tests;</li> <li>Laboratory works;</li> <li>Problem solving;</li> <li>Additional points for presentations</li> </ul> |

| Content: breakdown of the topics                                                                                                                                                                                                    | Contact hours |           |          |           |                 |                           |               | Self-study work: time and assignments |                                                      |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|-----------|----------|-----------|-----------------|---------------------------|---------------|---------------------------------------|------------------------------------------------------|
|                                                                                                                                                                                                                                     | Lectures      | Tutorials | Seminars | Exercises | Laboratory work | Internship/work placement | Contact hours | Self-study hours                      | Assignments                                          |
| 1. Wave function. The Schrodinger Equation. Statistical interpretation. Propability. Normalization. Uncertainty Principle.                                                                                                          | 2             | 1         |          | 2         |                 |                           | 5             | 2                                     | Textbook reading, studies for seminars and tutorials |
| 2. Wave function. The Schrodinger Equation. Statistical interpretation. Propability. Normalization. Uncertainty Principle.                                                                                                          | 3             | 1         |          | 2         |                 |                           | 6             | 3                                     | Textbook reading, studies for seminars and tutorials |
| 3. Transmission and reflection at a barrier, potential wells, the simple harmonic oscillator, the free particle.                                                                                                                    | 3             | 1         |          | 2         |                 |                           | 6             | 3                                     | Textbook reading, studies for seminars and tutorials |
| 4. Formalism. Hilbert space. Observable. Operators. Eigenfunctions. Eigenvalues. Dirac notation.                                                                                                                                    | 3             | 1         |          | 2         |                 |                           | 6             | 3                                     | Textbook reading, studies for seminars and tutorials |
| 5. Central potential and introduction to hydrogenic systems.                                                                                                                                                                        | 3             | 1         |          | 2         |                 |                           | 6             | 3                                     | Textbook reading, studies for seminars and tutorials |
| 6. Time-independet perturbation theory.                                                                                                                                                                                             | 3             | 1         |          | 2         |                 |                           | 6             | 3                                     | Textbook reading, studies for seminars and tutorials |
| 7. Time-dependent perturbation theory. Fermi's golden rule.                                                                                                                                                                         | 3             | 1         |          | 2         |                 |                           | 6             | 3                                     | Textbook reading, studies for seminars and tutorials |
| 8. Periodic potential.                                                                                                                                                                                                              | 2             | 1         |          | 2         |                 |                           | 5             | 2                                     | Textbook reading, studies for seminars and tutorials |
| 9. Introduction. Paradigms of solid state and condensed matter. Scope of interest, typical objects, sizes, energies, boundaries of the semi-classical and quantum-mechanical interpretation. Concept of broken symmetry.            | 2             | 1         |          | 2         |                 |                           | 5             | 2                                     | Textbook reading, studies for seminars and tutorials |
| 10. Crystal binding. Asymmetrical potential of interatomic interactions. Ionic, covalent, Van der Waals, metallic and hydrogen binding, properties, potentials.                                                                     | 2             | 1         |          | 2         |                 |                           | 6             | 2                                     | Textbook reading, studies for seminars and tutorials |
| 11. Crystal structure. Main definitions. Elements of symmetry in crystals, translational and rotational symmetry operations. Bravais lattice, primitive cell, lattice with a basis. Most common crystal structures. Miller indices. | 4             | 1         |          | 2         |                 |                           | 7             | 4                                     | Textbook reading, studies for seminars and tutorials |

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| 12. X-Ray diffraction. Reciprocal lattice, definition and properties. Brillouin zones. X-Ray structural analysis, its history and applicability. Bragg and von Laue diffraction laws. Geometries of an X-ray experiment. Structure and atomic form factors.                                                                                                                                                                                                                                                                                                                                                                                                  | 4 | 1 |  | 2 |    |  | 7  | 4  | Textbook reading, studies for seminars and tutorials                                                             |
| 13. Defects in solid state, their impact on the mechanical properties. Definition of defects, classification, examples. Point defect types, vacancies, colour centres. Schottky and Frenkel type defects. Point defect diffusion in a crystal. Positron annihilation spectroscopy. Edge and screw type dislocations. Burgers vector. Dislocation movement in a crystal, related strain, energy, interactions with other defects. Source of dislocations. 2D and 3D defects: packing defects, domains, surfaces, precipitates. Mechanical properties of crystals, strain and deformation, Hooke's law. Dislocation impact on mechanical properties of solids. | 4 | 1 |  | 3 | 4  |  | 11 | 7  | Textbook reading, studies for seminars and tutorials. Laboratory works, analysis and presentation of the results |
| 14. Crystal vibrations. Elastic vibrations in homogeneous and anisotropic media. Dispersion relation, phase and group velocity. Physical importance of the first Brillouin zone. Periodic boundary conditions. Phonon definition. Optical and acoustical branches. Examples of dispersion relations in real crystals.                                                                                                                                                                                                                                                                                                                                        | 3 | 1 |  | 2 |    |  | 6  | 3  | Textbook reading, studies for seminars and tutorials                                                             |
| 15. Thermal properties of crystals. Definition of heat capacity. Density of states function. Dulong-Petit, Einstein and Debaye models. Input of free electrons to heat capacity. Thermal expansion. Phonon thermal conductivity, U and N phonon processes. Thermal conductivity of electrons. Phonon scattering by defects.                                                                                                                                                                                                                                                                                                                                  | 3 | 1 |  | 2 |    |  | 6  | 3  | Textbook reading, studies for seminars and tutorials                                                             |
| 16. Electrons in crystals. Classical Drude electron model. Fermi energy (level). Schrödinger equation for a crystal. Adiabatic and single electron approximations. Bloch theorem. Electron energy spectrum in 1D crystal, energy bands, forbidden energy bandgap, examples in real crystals. Effective mass, concept of a hole, quasi-momentum. Defect energy states. Semiconductor, dielectric, metal. Free carrier density in intrinsic and doped semiconductor. Mobility. Electrical conduction of semiconductors and metals. Basics of carrier transport, Boltzmann equation.                                                                            | 6 | 1 |  | 4 | 20 |  | 31 | 17 | Textbook reading, studies for seminars and tutorials. Laboratory works, analysis and presentation of the results |
| 17. Light and matter interaction. Main optical processes and coefficients. Complex dielectric constant. Classical oscillator, Kramers-Kronig relations. Direct and indirect gap materials. Light absorption and photoluminescence. Golden Fermi rule. Joint density of states. Light absorption in electric and magnetic fields.                                                                                                                                                                                                                                                                                                                             | 4 | 1 |  | 2 | 4  |  | 11 | 5  | Textbook reading, studies for seminars and tutorials. Laboratory works, analysis and presentation of the results |
| 18. Quantum and carbon structures. Quantum confinement. Quantum well, quantum wire, quantum dot. Density of states and electron energy in quantum structures. Types of quantum                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 3 | 1 |  | 2 |    |  | 6  | 3  | Textbook reading, studies for seminars and tutorials                                                             |

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| wells and growth techniques. Quazicrystals, disordered systems, carbon structures.                                                                                                                                                                                                 |           |           |  |           |           |          |            |           |                                                      |
| 19. Magnetic properties. Main definitions and parameters. Diamagnetics, paramagnetics, ferromagnetics. Microscopic origin of diamagnetism, paramagnetism, and ferromagnetism. Magnetism of metals. Spin waves, magnons. Antiferromagnetism and ferrimagnetism. Magnetic resonance. | 3         | 1         |  | 2         |           |          | 6          | 3         | Textbook reading, studies for seminars and tutorials |
| 20. Superconductivity. Critical temperature. Low and high temperature superconductivity. Properties of superconductors, type I and type II superconductors. Physical origin of superconductivity, Cooper pairs. London and BCS theories.                                           | 3         | 1         |  | 2         |           |          | 6          | 3         | Textbook reading, studies for seminars and tutorials |
| Intermediate tests                                                                                                                                                                                                                                                                 |           |           |  | 2         |           | 2        | 4          | 6         | Preparation for test                                 |
| Final exam                                                                                                                                                                                                                                                                         |           |           |  |           |           | 2        | 2          | 6         | Preparation for exams                                |
| <b>Total</b>                                                                                                                                                                                                                                                                       | <b>64</b> | <b>20</b> |  | <b>44</b> | <b>28</b> | <b>4</b> | <b>160</b> | <b>90</b> |                                                      |

| Assessment strategy | Weight, % | Deadline       | Assessment criteria                                                                |
|---------------------|-----------|----------------|------------------------------------------------------------------------------------|
| Problem solving     | 20        | During term    | Ability to solve problems                                                          |
| Laboratory works    | 20        | During term    | Quality of laboratory work performance and presentation, understanding of the work |
| Intermediate tests  | 30        | During term    | Semi-open book tests with short questions and basic problems under limited time    |
| Final exam          | 30        | During session | Semi-open book tests with short questions and basic problems under limited time    |

| Author                    | Year of publication | Title                                    | Issue of a periodical or volume of a publication | Publishing place and house or web link |
|---------------------------|---------------------|------------------------------------------|--------------------------------------------------|----------------------------------------|
| <b>Compulsory reading</b> |                     |                                          |                                                  |                                        |
| D. J. Griffiths           | 2005                | Introduction to Quantum Mechanics        |                                                  | Prentice Hall                          |
| C. Kittel                 | 2005                | Introduction to Solid State Physics      |                                                  | John Wiley & Sons                      |
| P. Hoffman                | 2008                | Solid State Physics                      |                                                  | Wiley-VCH                              |
| <b>Optional reading</b>   |                     |                                          |                                                  |                                        |
| V. Karpus                 | 2002                | Kietujų kūnų fizika                      |                                                  | Ciklonas                               |
| F. Duan, J. Guojun        | 2005                | Introduction to Condensed Matter Physics |                                                  | World Scientific Publishing            |