Physics of Condensed Matter and Materials

Coordinated by: Department of Condensed Matter Physics
Study programme coordinator: doc. RNDr. Stanislav Daniš, Ph.D.

Characterization of the study program:

The programme is devoted to experimental and theoretical study of properties of condensed systems, their microphysical interpretation and possible applications, in particular with respect to the current development of materials research. In addition to common study, the students can select one of the following specializations: Physics of atomic and electronic structures, Physics of macromolecular compounds, Physics of materials, Low temperature physics, Physics of surface modifications. Each of these blocks ensures a general education in condensed matter physics at the contemporary level of knowledge and shapes the graduate in selected specialization.

Profile of the graduates and aims of the study:

Graduates acquire a broad education in the fundamentals of quantum theory, thermodynamics and statistical physics of condensed systems and the corresponding computing methods. They are able to describe the structure of the systems in different forms, their mechanical, electrical, magnetic and optical properties. They have a general knowledge of experimental methods of characterizing the structure, composition and properties of condensed compounds through for example diffraction, spectroscopic and microscopic techniques, and they are able to apply them in practice. Graduates are able to find suitable positions in institutions of basic physical, chemical and biomedical research, universities, applied research laboratories, testing laboratories, and in hygiene and ecology institutions.

The aim of the study is to provide a broad education in quantum theory, thermodynamics and statistical physics in connection with current approaches to the theory, inorganic organic and macromolecular condensed systems. At the same time, it is the goal of the study to provide students with an overview of the principles of modern experimental methods and technological procedures. In the chosen specialization, students are provided with a deeper education and practical skills.

Recommended plan of the study

First year of the of the Master study

A pre-requisite of the study in this program is knowledge of quantum theory, solide state physics, soft condensed matter physics and condensed system physics on the Bachelor level.

Compulsory and compulsory-optional courses (25 credits from compulsory elective subjects for the basic base).

Students choose one of the five specializations: Physics of atomic and electronic structures, Physics of macromolecular substances, Physics of materials, Low temperature Physics and Physics of surface modifications.

First year of the Master study

Code	Subject	Credits	Winter	Summer
NFPL145	**Experimental Methods of Condensed Systems Physics I**	9	3/3 C+Ex	—

NFPL146	**Experimental Methods of Condensed Systems Physics II**	9	—	3/3 C+Ex
NFPL800	**Thermodynamics of Condensed Matter**	5	2/1 C+Ex	—
NFPL801	**Seminar** [1]	3	0/2 C	—
NFPL802	**Seminar** [1]	3	—	0/2 C
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
Physics of atomic and electronic structures				
NFPL143	Solid State Physics I	9	4/2 C+Ex	—
NFPL144	Structure of Matter and Structure Analysis	7	3/2 C+Ex	—
NFPL147	Solid State Physics II	9	—	4/2 C+Ex
Physics of macromolecular substances				
NBCM066	Introduction to Macromolecular Chemistry	5	2/1 C+Ex	—
NBCM208	Fundamentals of Macromolecular Physics	4	—	3/0 Ex
NBCM058	Relaxation Behaviour of Polymers	3	—	2/0 Ex
NBCM038	Electrical and Optical Properties of Polymers	3	—	2/0 Ex
NBCM231	Applied Thermodynamics	3	—	2/0 Ex
Physics of materials				
NFPL132	Condensed Matter Theory	6	3/1 C+Ex	—
NFPL133	Structure of Materials	4	3/0 Ex	—
NFPL135	Physics of Materials I	4	2/1 C+Ex	—
NFPL139	Physics of Materials II	4	—	2/1 C+Ex
NFPL137	Technology of Materials	3	—	2/0 Ex
NFPL136	Special practical courses of physics of materials	4	—	0/3 C
Low Temperature Physics				
NFPL143	Solid State Physics I	9	4/2 C+Ex	—
NFPL168	Low Temperature Physics and Techniques	3	2/0 Ex	—
NFPL103	Positron Annihilation in Solids	3	2/0 Ex	—
NFPL169	Hyperfine Interactions and Nuclear Magnetism	3	—	2/0 Ex
NFPL092	Radiofrequency Spectroscopy of Solids	3	—	2/0 Ex
NFPL206	Selected topics of quantum theory of solids	7	—	3/2 C+Ex
Physics of surface modifications				
NBCM066	Introduction to Macromolecular Chemistry	5	2/1 C+Ex	—

NBCM213	Physics of Thin Film Preparation	3	2/0 Ex	—
NBCM233	Analysis Methods of Surfaces and Thin Layers	5	2/1 C+Ex	—
NBCM214	Plasma Polymerisation Processes	3	2/0 Ex	—
NBCM231	Applied Thermodynamics	3	—	2/0 Ex

[1] As a Field Seminar, students attend one of the following seminars: Structural Seminar analysis (NFPL037), Condensed matter theory seminar (NFPL062), Magnetism seminar (NFPL118), Low Temperature Physics Seminar (NFPL098), Materials Physics Seminar (NFPL113), Polymer Physics Seminar (NBCM091), Plasma Polymer Study Seminar (NBCM200).

Second year of the Master study

Code	Subject	Credits	Winter	Summer
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NFPL124	**Experimental methods of condensed matter physics III**	6	2/2 C+Ex	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
Physics of atomic and electronic structures				
—				
NBCM217	Modern Trends in Macromolecular Physics	4	3/0 Ex	—
NBCM142	Diploma Thesis Seminar	3	—	0/2 C
Physics of materials				
—				
Low Temperature Physics				
—				
Physics of surface modifications				
NBCM219	Selected Problems in Physics of Real Surfaces	3	2/0 Ex	—
NBCM142	Diploma Thesis Seminar	3	—	0/2 C

Compulsory-optional courses - 15 credits

Code	Subject	Credits	Winter	Summer
Physics of atomic and electronic structures				
NFPL115	Electron Microscopy	3	2/0 Ex	—
NFPL122	Magnetic Properties of Solids	3	2/0 Ex	—
NFPL014	Dielectric Properties of Solids	3	2/0 Ex	—
NFPL040	Applied Structure Analysis	3	—	1/1 C+Ex
NFPL154	Neutron and Synchrotron Radiation in Magnetic Materials	6	—	2/2 C+Ex

NFPL030	X-ray methods for structure and microstructure investigation of materials	5	—	2/1 C+Ex
NFPL082	Magnetism and Electronic Structure of Metallic Systems	3	2/0 Ex	—
NFPL013	X-ray Scattering on Thin Films	3	2/0 Ex	—
NFPL155	Experimental Study of Real Structure of Solids	4	2/1 C+Ex	—
NFPL157	Physics in Strong Magnetic Fields	3	2/0 Ex	—
NFPL156	High Pressure Physics	3	2/0 Ex	—
NFPL158	Magnetic Structures	4	2/2 C+Ex	—
NFPL550	Thermal Capacity of Solids	3	2/0 Ex	—
NFPL011	Computational Physics and Materials Design	3	2/0 Ex	—
NFPL004	Nonequilibrium Statistical Physics and Thermodynamics	3	2/0 Ex	—
NFPL039	Methods of Solving and Refining Monocrystal Structures	3	—	1/1 C+Ex
NFPL159	Modern Materials with Application Potential	3	—	2/0 Ex
NFPL551	Correlations in Many-Electron Systems	3	—	2/0 Ex

Physics of macromolecular substances

NBCM098	X-ray and Electron Structure Analysis of Biomolecules and Macromolecules	3	2/0 Ex	—
NBCM211	Methods of Measuring Electric Properties of Semiconducting and Insulating Materials	3	1/1 C+Ex	—
NFPL018	Transport and Surface Properties of Solids	3	2/0 Ex	—
NBCM230	NMR Spectroscopy of Polymers	3	—	2/0 Ex
NBCM209	Probabilistic Methods in Macromolecular Physics	3	—	2/0 Ex
NBCM076	Theory of Polymer Structures	3	2/0 Ex	—
NBCM072	Fundamentals of Molecular Electronics	3	2/0 Ex	—
NBCM062	Structural Theories of Polymer Relaxation Behaviour	3	2/0 Ex	—

Physics of materials

NFPL107	Fundamentals of Crystallography	3	1/1 C+Ex	—
NFPL115	Electron Microscopy	3	2/0 Ex	—
NFPL055	Kinetics of Phase Transformations	3	—	2/0 Ex
NFPL305	Magnetism of Materials	3	—	2/0 Ex

NFPL197	Fundamentals of Continuum Mechanics and Dislocation Theory	3	—	2/0 Ex
NFPL198	Theory of crystal defects	3	—	2/0 Ex
NFPL080	Acoustic in Physics of Condensed Matter	6	—	3/1 MC
NFPL140	Physics of Materials III [1]	3	2/0 Ex	2/0 Ex
NFPL103	Positron Annihilation in Solids	3	2/0 Ex	—

Low Temperature Physics

NFPL171	Macroscopic Quantum Phenomena I	3	2/0 Ex	—
NFPL172	Macroscopic Quantum Phenomena II	3	—	2/0 Ex
NFPL093	Selected Topics on Magnetic Resonance Theory and Methodology	3	2/0 Ex	—
NFPL097	Nuclear Spectroscopy Methods in Hyperfine Interaction Studies	3	—	1/1 C+Ex
NFPL174	Introduction to Fluid Dynamics and Turbulence	3	2/0 Ex	—
NFPL210	Turbulence	3	2/0 Ex	—
NFPL096	Moessbauer Spectroscopy	3	2/0 Ex	—
NFPL175	NMR in Magnetically Ordered Materials	3	1/1 C+Ex	—
NFPL129	Nuclear Methods in Magnetic Systems Studies	3	2/0 Ex	—
NFPL095	Fundamentals of Cryogenics	3	2/0 Ex	—
NFPL128	Selected Topics on Positron Annihilation Spectroscopy	3	1/1 C+Ex	1/1 C+Ex
NFPL184	Seminar on Radiofrequency Spectroscopy in Condensed Matter	3	0/2 C	0/2 C
NFPL204	Magnetic nanoparticles	3	2/0 Ex	—
NFPL179	Quantum Description of NMR	5	—	2/1 C+Ex

Physics of surface modifications

NFPL107	Fundamentals of Crystallography	3	1/1 C+Ex	—
NBCM234	Construction of Deposition Apparatuses	5	2/1 C+Ex	—
NBCM235	Basics of Plasma Physics	3	2/0 Ex	—
NFPL149	X-ray Study of Real Structure of Thin Films	3	—	2/0 Ex
NBCM215	Modification of Surfaces and Its Applications	3	—	2/0 Ex
NBCM236	Nanocomposite and Nanostructured Thin Layers	3	—	2/0 Ex
NBCM220	Hard and Super-hard Films and Their Applications	3	2/0 Ex	—
NBCM232	Electrical Properties of Thin Layers	3	2/0 Ex	—

NBCM222	Optical Properties of Thin Films	3	2/0 Ex	—

[1] The course can be enrolled in either the summer or winter semester.

Physics of Condensed Matter and Materials - optional subjects

Code	Subject	Credits	Winter	Summer
NFPL038	*Diffraction of X-rays by Perfect Crystals*	3	2/0 Ex	—
NFPL130	*Physical Metallurgy of Wrought Aluminium Alloys*	3	2/0 Ex	—
NFPL199	*Physical Methods in Nanostructure Studies*	3	—	2/0 Ex
NEVF106	*Microscopy of Surfaces and Thin Films*	5	2/1 C+Ex	—
NFPL120	*Modern Problems in Physics of Materials*	3	2/0 Ex	—
NFPL006	*High Performance Computing in Physics*	3	1/1 C+Ex	—
NFPL177	*Superconductivity*	5	2/1 C+Ex	—
NFPL072	*Systems with Correlated f-electrons*	3	2/0 Ex	—
NFPL141	*Quantum Theory II*	5	2/1 C+Ex	2/1 C+Ex
NFPL051	*Mechanical Properties of Non-metallic Materials*	3	2/0 Ex	—
NFPL500	*Practical application of atomic force microscopy*	2	—	0/2 C
NFPL192	*Introductory Seminar on Condensed Systems Physics*	3	—	0/2 MC
NFPL505	*Introduction to Soft Condensed Matter Physics*	3	—	1/1 C+Ex
NFPL502	*Introduction to Solid State Physics*	6	—	3/1 C+Ex
NBCM060	*Fundamentals of Polymer Structure Formation*	3	—	2/0 Ex
NFPL074	*Practical Applications of Transmission Electron Microscopy*	4	0/3 C	0/3 C

Conditions that must be satisfied to register for the state final exam

– gain of at least 120 credits
– passing all compulsory courses of the chosen specialization
– gain of at least 25 credits from compulsory-optional courses of the profiling base
– gain of at least 15 credits from compulsory-optional courses
– submission of the completed diploma thesis within the given deadline

Requirements for the oral part of the state final exam

A. Common requirements

Band structure and methods of its calculation: one-electron approximation and methods for solving effective equations (LCAO method, nearly free electrons, LAPW,

pseudopotentials). Adiabatic approximation, variational principle and perturbation theory.

Interaction between electrons - second quantization, Hartree-Fock approximation, theory of density functional. Quasiparticles in condensed systems.

Interaction of electromagnetic radiation with matter - photon absorption and emission. Stimulated and spontaneous emissions, selection rules. Lifetime of quantum states, natural spectral line width.

2. Thermodynamics and statistical physics of condensed systems

Thermodynamic equilibrium, state quantities and equations of state. Main thermodynamics sentences and their consequences, entropy and absolute temperature. Thermodynamic potentials, conditions of balance and stability. Critical phenomena, phase transitions, Landau's phase transitions theory. Description of nonequilibrium processes, linear nonequilibrium thermodynamics. Statistical description of state, distribution function and density matrix. Liouville's equation. Gibbs stationary files, file centering, derivation of state equations. Classic and quantum systems of non-interacting particles. Brownian motion, diffusion in the external field.

3. Fundamentals of condensed matter physics

Structure of condensed systems - crystal structure, point and translational symmetry, basics of crystallography. Reciprocal space, Brillouin zone.

Real structure of substances - defects of crystal structure, long and short -term ordering. Amorphous substances and their description, pair distribution functions. Description of topology, spatial and electronic structure of macromolecules.

Movement of atoms and molecules in condensed matter - diffusion, lattice oscillations, phonons, heat capacity.

Electrical properties - polarization mechanisms, dielectric susceptibility. Interaction of ionic crystal lattice with electromagnetic wave. Electric current transport - Sommerfeld model, electrons in the periodic potential, band structure of metals and semiconductors. Basic knowledge of superconductivity.

Magnetic properties - diamagnetism and paramagnetism, magnetization, magnetic susceptibility. Spontaneous alignment of magnetic moments. Magnetization processes in ferromagnets.

Mechanical force field - elastic and plastic deformation, viscosity. Viscoelasticity and rubber elasticity of polymer systems, glass transition, principle of time-temperature superposition.

4. Experimental methods

Structure determination methods - basic diffraction methods: scattering and diffraction of x-rays, electrons, neutrons, atoms and ions. Microscopic methods - optical, scanning and transmission electron microscopy.

Macroscopic and microscopic methods of studying mechanical, thermal, dielectric, optical, transport and magnetic properties of matter.

Basic spectroscopic methods (radio frequency, microwave, optical, X – ray, gamma, photoemission) and their applications.

B. Specializations

The student chooses a set of questions corresponding to his specialization.

1. Physics of atomic and electronic structures

Atomic structure of matter

Point and space groups. Symmetry of physical properties. Structure of crystals, quasicrystals, modulated structures and amorphous substances. Using of structural databases. Kinematic theory of diffraction - scattering of x-rays on electrons, atoms and molecules; dispersion on periodic and low-dimensional structures. Fundamentals of dynamic theory of diffraction. Use of neutrons and synchrotron radiation to study the structure of matter. Computer simulations, ab-initio calculations.

Electron structure and physical properties of substances

Conductivity electrons in materials (classical and quantum description), electrons in periodic potential. Electronic structure of metals, semiconductors and insulators, optical properties. Chemical bonding, cohesion, hybridization of electronic states. Electron-phonon interaction, electrical and thermal transport. Coulomb and exchange interaction, correlations of electrons, the formation of magnetic moment. Magnetic ordering, symmetry. Microscopic models of magnetism. Low dimensional systems. Specific heat, temperature dilatation. Magnetotransport and magnetoelastic phenomena. Dielectrics, electrical permittivity, ferroelectrics and antiferroelectrics. Electro-optical and magneto-optical phenomena. Utilization of microscopic and macroscopic methods. Influence of external pressure, physics in high magnetic fields. Ab initio calculations of electronic structure and physical properties. Applications of electronic properties of materials. Nanomaterials.

Collective phenomena

Spontaneous symmetry breaking and the ordering parameter. Microscopic description of phase transitions, mean field theory, fluctuations. Structural and magnetic phase transitions. Spontaneous ordering of nuclear moments. Kondo lattice and heavy fermion systems. Bose-Einstein condensation of an atom. Superconductivity and superfluidity. Cooperative phenomena out of equilibrium, lasers.

2. Physics of macromolecular substances

Structure of macromolecules

Configuration, conformation, tacticity and stereoregularity of polymer chains. Architecture of macromolecular systems. Methods of preparation of macromolecular systems, chemical structure of polymers, methods of construction of polymer networks, gelation point. Distribution and molar mass averages.

Physical properties of macromolecular systems

Relaxation properties, glass transition and free volume theory, time-temperature superposition. Concept of linear viscoelasticity, viscoelastic functions, Boltzmann's principle of superposition. Thermodynamics of polymer solutions, mixtures and block copolymers, phase diagrams. Flory-Huggins theory, swelling equilibrium. Colligative properties of polymers, solutions. Coil-globule transition. Crystallization of polymers. Electrical and optical properties of polymers, generation and charge transport in organic structures.

Experimental methods

Methods of studying the glass transition, measuring of rheological and viscoelastic properties, dynamic mechanical analysis. Measurement of dielectric and electrical properties, thermal depolarization. Detection of thermal transitions, differential scanning

calorimetry. Methods for determining the molecular weights and structure of polymers. Diffraction / scattering and spectroscopic methods for studying the structure of macromolecular systems.

3. Physics of materials

Defects of crystal lattice

Crystal lattice, vacancies, interstitials, stacking faults, sub boundaries, grain boundaries, twins, inclusions, dispersoids, precipitates. Interaction of crystal lattice defects. Experimental methods of studying crystal defects: mechanical tests, diffraction and imaging methods, thermal analysis, acoustic emission.

Mechanical properties

Plastic deformation, theory of strengthening, creep and fracture. Static and dynamic softening, recovery of lattice defects, superplasticity, instability of plastic deformation, shape memory.

Thermodynamics of multicomponent systems

Binary and ternary phase diagrams, nearest neighbors model, lever rule, intermedial phase. Phase transformations, solidification of alloys, segregation processes. Diffusion and diffusionless transformations in solids, TTT-diagrams, Avrami equations. Diffusion in solids.

Modern materials and technologies

Intermetallic compounds, ceramic and composite materials, submicrocrystalline and nanocrystalline materials, quasicrystals, shape memory materials, technologies of preparation of modern materials.

4. Low Temperature Physics

Electronic structure of solids

Methods of electronic structure calculation. Electronic structure and magnetic properties of solids. Magnetic moments of free atom / ion, interaction with crystal field, correlation phenomena, exchange interactions, localized and itinerant magnetic moments.

Physics and technology of low temperatures

Methods of obtaining low and very low temperatures, basic properties of cryofluids. Low temperature thermometry.

Macroscopic quantum phenomena

Superconductivity, Cooper pairs, Meissner effect, weak superconductivity. Superconductors of type I. and II., high temperature superconductivity. Superfluidity of ^{4}He, ^{3}He, macroscopic wave function, Bose-Einstein condensation.

Hyperfine interactions and nuclear magnetism

Electric and magnetic moments of atomic nuclei, electric and magnetic hyperfine interaction. Spin Hamiltonian, hyperfine splitting of energy levels, the role of symmetry of the nucleus vicinity.

Experimental methods of studying hyperfine interactions (nuclear magnetic resonance, electron paramagnetic resonance, muon spin rotation, Mössbauer's effect, nuclear orientation, method of perturbed angular correlations) and their use for study of atomic, electronic and magnetic structures.

5. Physics of real surfaces

Surface physics

Molecule binding on the surface, absorption, ideal and real surface, electronic structure of surfaces, surface states, work function, emission of charged particles, electron emission, principle of electron spectroscopy, interaction of particles and radiation with the surface, photoemission, principle of photoelectron spectroscopy, secondary electron emissions, diffraction. Energy of surfaces and interfaces.

Experimental methods of surface study

Electron spectroscopy methods (AES, REED), ion spectroscopy methods (SIMS, SNMS), methods of photoelectron spectroscopy (UPS, XPS) and their practical use. Methods of electron microscopy. Surface energy measurement: static and dynamic methods of measuring the contact angle. Infrared spectroscopy ATR FTIR, methods of X-ray diffraction — small - angle scattering.

Preparation of thin layers

Thin film definition, concept of thin film thickness, initial stage and mechanisms of layer growth. Basic methods of their preparation: evaporation in vacuum, DC and radio-frequency (RF) spraying, CVD, PE CVD of inorganic and organic layers (plasma polymerization). Methods of diagnostics of thin film growth, measurement of growth rate and layer thickness, determination of structure and morphology, mechanical, electrical and optical properties. Surface modifications, changes in surface energy and chemical activity. Application of thin films — hard, abrasion resistant coatings, protective and passivation layers, optical thin films, layers for microelectronics.