The field of PHYSICS

Faculty of mathematics and physics offers twelve English programmes of doctoral studies, which cover completely this discipline including related interdisciplinary fields.

P4F1A Theoretical Physics, Astronomy and Astrophysics
P4F2A Physics of Plasmas and Ionized Media
P4F3A Physics of Condensed Matter and Materials Research
P4F4A Biophysics, Chemical and Macromolecular Physics
P4F5A Physics of Surfaces and Interfaces
P4F6A Quantum Optics and Optoelectronics
P4F7A Physics of the Earth and Planets
P4F8A Atmospheric Physics, Meteorology and Climatology
P4F9A Particle and Nuclear Physics
P4F11A Mathematical and Computer Modeling
P4F12A Physics Education and General Problems of Physics
P4F13A Physics of Nanostructures and Nanomaterials

Besides departments and institutes of the faculty, fifteen institutes of the Czech Academy of Sciences (CAS) participate in the education of doctoral students.

Available topics of the dissertations are listed in the student information system (SIS) at http://mff.cuni.cz/phd/temata/*kód programu*.

The most of doctoral programmes offer selected dissertation topics with extended financial support. They are described in details at `https://www.mff.cuni.cz/en/physicsphd/` . The candidates apply for these topics in advance and pass a preliminary admission procedure. Successful applicants undergo then simplified admission procedure.

Study programme P4F1A Theoretical Physics, Astronomy and Astrophysics

Annotation

The programme P4F1A covers two broad areas: 1) theoretical physics and 2) astronomy and astrophysics. In the former area, it focuses mainly on gravitational and relativistic physics, cosmology, theoretical astrophysics, atomic and molecular physics, mathematical physics, theoretical aspects of plasma, high energy physics including string theory and ADS/ CFT correspondence, and some aspects of particle physics. In the latter area, it is focused on applied astrophysics and both theoretical and observational astronomy.

Board of the doctoral programme

Members of the board: `http://mff.cuni.cz/phd/or/p4f1` .

Cooperating institutes

- Astronomical Institute, CAS
  Fričova 298, 251 65 Ondřejov
  `http://www.asu.cas.cz/`

- Institute of Physics, CAS
  Na Slovance 2, 182 21 Praha 8
  `http://www.fzu.cz/`

- Institute of Mathematics, CAS
  Žitná 25, 115 67 Praha 1
  `http://www.math.cas.cz`

- J. Heyrovsky Institute of Physical Chemistry, CAS
  Dolejškova 2155/3, 182 23 Praha 8
  `http://www.jh-inst.cas.cz/`

- Nuclear Physics Institute, CAS
  Husinec – Řež č. p. 130, PSČ 250 68
  `http://www.ujf.cas.cz/`

Available topics of the dissertation

Topics are listed in SIS at `http://mff.cuni.cz/phd/temata/p4f1`.

Courses

The student must complete the compulsory lectures of the master's study program at the FMP CU in the field corresponding to her/his specialization if she/he has not already completed them within his master's degree. In addition, the student chooses from advanced Master's and doctoral lectures offered by the study programs Astronomy and Astrophysics, Theoretical Physics, Physics of Condensed Matter and Materials Research, Particle and Nuclear Physics, and Mathematical and Computer Modeling. Doctoral students can choose especially among the following advanced lectures:

Code	Subject	Winter	Summer
NAST004	**Galactic and Extragalactic Astronomy II**	3/0 Ex	—
NAST008	**Cosmic Electrodynamics**	3/1 C+Ex	—
NAST011	**Celestial Mechanics II**	—	4/0 Ex
NAST021	**Selected chapters on astrophysics**	2/0 Ex	—
NAST030	**Active Galaxies**	—	2/0 Ex
NAST038	**Advanced methods of solar physics**	2/0 Ex	—
NAST040	**Introduction to radioastronomy**	2/0 Ex	—
NMAF006	**Selected Topics on Mathematics for Physicists**	—	2/0 Ex
NTMF022	**Theory of Gauge Fields**	3/0 Ex	—
NTMF024	**Advanced Simulations in Many-particle Physics**	—	2/0 Ex

NTMF025	**Selected Chapters on Mathematical Physics**	—	2/0 Ex
NTMF030	**Quantum scattering theory**	3/1 C+Ex	—
NTMF038	**Relativistic Physics II**	—	4/2 C+Ex
NTMF058	**Computer Methods in Theoretical Physics II**	—	2/1 C+Ex
NTMF059	**Geometrical Methods of Theoretical Physics I**	2/2 C+Ex	—
NTMF060	**Geometrical Methods of Theoretical Physics II**	—	3/0 Ex
NTMF061	**Group Theory and its Applications in Physics**	2/2 C+Ex	—
NTMF063	**Selected Topics on General Relativity I**	2/0 Ex	—
NTMF064	**Symmetries of Equations of Mathematical Physics and Conservation Laws**	—	2/0 Ex
NTMF065	**Introduction to quantum field theory on curved background**	2/1 Ex	—
NTMF068	**Selected Chapters on Nonequilibrium Statistical Physics II**	—	2/0 Ex
NTMF070	**Radiative Processes in Astrophysics**	—	2/0 Ex
NTMF073	**Selected Topics on General Relativity II**	2/0 Ex	—
NTMF088	**Exact Spacetimes**	—	2/0 Ex
NTMF089	**Gravitational Waves I**	—	2/0 Ex
NTMF090	**Astrophysics of gravitational wave sources**	—	2/0 Ex
NTMF091	**Black hole thermodynamics: classical and quantum**	—	2/0 Ex
NTMF095	**Advanced topics in quantum field theory on curved background**	—	2/0 Ex
NTMF099	**Gravitational Waves II**	—	2/0 Ex
NTMF101	**New developments in astrophysics and theoretical physics**	0/1 C	0/1 C
NTMF107	**Foundations of Numerical Study of Spacetimes**	3/0 Ex	—
NTMF130	**Theory of collisions of atoms and molecules**	—	3/1 C+Ex
NTMF333	**Theoretical Cosmology II**	—	2/0 Ex
NFPL109	**Condensed Matter Theory II**	2/0 Ex	—
NJSF044	**Mathematical Methods of Quantum Theory II**	—	2/0 Ex
NJSF047	**Selected topics on the superstring theory**	—	2/1 Ex
NJSF061	**Quantum Field Theory II**	—	4/2 C+Ex
NJSF069	**Quantum Field Theory II**	—	4/2 C+Ex
NJSF071	**Introduction to supersymmetry**	2/1 Ex	—
NJSF072	**Electroweak Interactions II**	2/1 Ex	—
NJSF079	**Quantum Field Theory III**	4/2 C+Ex	—

NJSF082	**Selected Topics on Quantum Field Theory I**	3/0 Ex	—
NJSF083	**Selected Topics on Quantum Field Theory II**	—	3/0 Ex
NJSF085	**Fundamentals of Electroweak Theory**	—	2/2 C+Ex
NJSF122	**Advanced Topics on Quantum Field Theory I**	3/0 Ex	—
NJSF123	**Advanced Topics on Quantum Field Theory II**	—	3/0 Ex
NJSF129	**Advanced Concepts of Symmetry**	—	2/2 Ex
NJSF139	**Beyond Standard Model Physics I**	2/1 Ex	—
NJSF140	**Beyond Standard Model Physics II**	—	2/1 Ex
NMMA331	**Introduction to Functional Analysis**	4/2 C+Ex	—
NMMA405	**Partial Differential Equations 1**	3/1 C+Ex	—
NMNV405	**Finite Element Method 1**	2/2 C+Ex	—

Requirements for the course of doctoral studies

a) In the first year, students should:
   complete 2 obligations* (typically by passing an exam);
   attend a regular seminar in their specialization;
   give a presentation at the Week of Doctoral Students conference organized by the faculty, or at an international conference in the field.

b) The student can enroll for the state doctoral examination after
   passing 4 obligations* and
   presenting her/his research results at the specialization seminar or at an international conference.

c) The condition for the defense and the completion of studies is a publication of two papers in international journals with an impact factor. The student should be the main author of at least one of the published works. The standard length of the study is 4 years.

d) It is expected (although it is not an obligatory condition for graduation) that the student will spend several months at a foreign institution during her/his studies. As an alternative, the student can attend summer or winter schools in the field.

*An obligation is typically a course listed in SIS concluded by an exam. It can be also a supervised reading (an individual lecture on a specialized topic). A fulfillment of such an exam is confirmed in SIS by the supervisor.

The Board will assess compliance individually. For example, it can accept that the student has only one exceptional publication in content or scope at the time of the defense.

Requirements for the doctoral exam

A doctoral student working in Theoretical Physics chooses two of the physical areas 1-6, one of which covers the area of her/his dissertation. The student also chooses one of the mathematical areas M1-M3.

A doctoral student working in Astrophysics or Astronomy chooses the area given by the topic of her/his work, one of the general areas A1, A2, and one of the physical areas 1-6.

Within the question concerning the thesis, the student acquaints the examination commission with the topic of her/his work and answers related questions.

1 Relativity and Cosmology
2 Quantum Field Theory and Particle Physics
3 Non-relativistic Quantum Theory
4 Solid State Physics
5 Hydrodynamics, Magnetohydrodynamics and Plasma Physics
6 Statistical Physics and Thermodynamics

M1 Differential Geometry, Lie Groups and Algebras
M2 Functional Analysis, Theory of Distributions, and Partial Differential Equations
M3 Numerical Methods

A1 Classical Astronomy, Astrodynamic and Experimental Methods in Astronomy
A2 Classical Astronomy, Astrodynamic and Theoretical Astrophysics

The exact scope of the examined areas is specified individually before the exam by the examiner. It depends on the completed lectures and the focus of the student research.

Physical areas cover in particular:

1 - Relativity and Cosmology

Fundamental principles of general theory of relativity, equations of geodesic and of geodetic deviation, Einstein field equations. Alternative theories of gravitation. Experimental methods in gravitational physics. Linearized theory and approximation methods. Theory of gravitational waves. Asymptotic structure of space-time and exact radiative solutions. Sources and detection of gravitational waves. Relativistic theory of stellar structure (white dwarfs, neutron stars, pulsars). Gravitational collapse and black-hole physics – general laws, astrophysical role of black holes. Initial problem and Hamiltonian formalism. Standard cosmological models and their tests, physics of early universe. Theory of linear perturbations of cosmological models.

2 - Quantum Field Theory and Particle Physics

The canonical formalism of the field theory. Feynman path integral, Feynman rules and perturbation theory. Quantum electrodynamics. Renormalization in the field theory. Gauge symmetry. Relativistic symmetry. CTP theorem. Spin and statistic. Non-abelian gauge theories. Renormalization group. Asymptotic freedom. Spontaneous symmetry breaking. Standard model. Unified interaction models. Supersymmetric field theory and string theories. Quantization in strong electromagnetic and gravitational fields, choice of vacuum, particle interpretation, Bogoljubov transformation.

3 - Non-relativistic Quantum Theory

Selfadjoint operators and their spectrum. Schrödinger equation, quasiclassical approximation, principle of superposition, uncertainty relations, stationary states, motion in spherically symmetric potential, perturbation theory, spin and spin states, identical particles, electronic structure of atoms, fine structure of atomic levels, atoms in electrical and magnetic fields, probability flux, elastic collisions, scattering amplitude, optical theorem, Born series, S-matrix and its properties and analytic structure, resonances, Jost function and Levinson theorem. Interpretation of quantum mechanics; decoherence and effective reduction, hidden-variable theory. Feynman formulation of quantum mechanics.

4 - Solid State Physics

Interacting electron gas in metals and semiconductors: electrostatic screening of electron-electron interaction and electron-phonon interaction, tight-binding models. Fermi liquid theory. Green's functions and their analytical properties, Kramers-Kronig relations, and fluctuation-dissipation theorem. Linear response theory, Kubo formulae. Superconductivity and superfluidity. BCS theory of superconductivity.

5 - Hydrodynamics, Magnetohydrodynamics and Plasma Physics

Boltzmann and Vlasov kinetic equations; general equations of (magneto)hydrodynamics; drift approximation of particle motions in electromagnetic fields; equilibrium and stability of plasma; dispersion relations for different types of waves in cold plasma; kinetic theory of waves in hot plasma; Landau damping and wave instability; non-linear wave interactions with plasma; trapped particles and quasilinear approximation of ponderomotive force in plasma; weak and strong turbulence in plasma; mutual interactions of waves; deterministic chaos – introduction to the theory and applications of anomalous phenomena in plasma; low-temperature, thermonuclear, and astrophysical plasmas.

6 - Statistical Physics and Thermodynamics

Statistical mechanics of interacting systems: classical and quantum liquids and gases, distribution function and perturbation methods — virial and cluster expansions, perturbation techniques in quantum statistical mechanics. Theory and models of phase transitions: Ising and Heisenberg models of magnetism, mean-field theory, scaling hypothesis, phase transitions and the renormalization group.

A1,A2 - Classical Astronomy...

Celestial mechanics: 2- and 3-body problem, theory of potential. Spherical astronomy: definitions of time, coordinate systems, transformations, corrections. Distance determination methods. Radiation transfer equation, Planck law, sources of opacity and emission. Basic concepts of stellar evolution (incl. Sun), Hertzsprung-Russel diagram. Observation of exoplanets. Interstellar medium, extinction. Binary stars, types of variable stars. Star formation, stellar populations, clusters. Milky Way, types of galaxies, structure, evolution of galaxies. Age determination methods. Basic concepts of cosmology, expansion factor, Hubble-Lemaitre law, lambda-CDM model.

A1 - ... and Experimental Methods

Telescope types, point-spread function, transfer function. aberration, diffraction, seeing, extinction. Definition of photometric quantities, signal and noise theory; CCD detectors, super-conducting detectors, photomultipliers, primary reduction. Direct imaging, adaptive optics, wavefront sensor, deconvolution. Photometry (aperture, PSF), standard system; astrometry; spectroscopy, reduction and calibration of spectra; polarimetry, Stokes parameters. Interferometry, visibility, van Cittert-Zernike teorem, supersyntesis. Radioastronomy, diagram, heterodyne receiver; radio interferometer, correlator, image reconstruction algorithms. Differences of IR, UV, X, gamma spectral bands; detectors of neutrinos and cosmic radiation; detectors of gravity waves, Michelson interferometer. Analysis of time series, light curve solution, radial velocity curve solution, Doppler tomography. Comparison of models and observations, inverse problem, chiχ2 metric, random and systematic uncertainties, Bayes theorem. Astronomical databases, archiving, Big Data.

A2 - ... and Theoretical Astrophysics

Equations of stellar structure, structure and evolution of stars, interacting binaries, late phases. State equation, degeneracy. Nucleogenesis in stars and after Big Bang. Solar physics; helioseismology and asteroseismology. Stellar atmospheres: Einstein coefficients, LTE vs. non-LTE, equations of statistical equilibrium, formation of spectral lines. Physics of planetary systems: N-body problem, tides, protoplanetary disks, non-gravitational effects. Atoms and molecules in interstellar space, electronic, vibrational and rotational spectra. Equations of magnetohydrodynamics (MHD), waves in plasma, thermal and non-thermal plasma radiation. Physics of accretion disks; shock waves.

Recommended literature

Binney, J., Merrifield, M.: **Galactic Astronomy.** *Princeton Series in Astrophysics, 1998.*

Binney, J., Tremain, S.: **Galactic Dynamics.** *Princeton Series in Astrophysics, 1988.*

Bowers, R., Deeming, T.: **Astrophysics I–III.** *Jones Bartlet, Boston, 1984.*

De Loore, C. W. H., Doom, C.: **Structure and Evolution of Single and Binary Stars.** *Kluwer, Dordrecht, 1992.*

M. Fecko: **Differential Geometry and Lie Groups for Physicists.** *Cambridge Univ. Press, Cambridge, 2011.*

Messiah, A.: **Quantum Mechanics, vols. III.** *North-Holland Publ. Comp., Amsterdam, 1961.*

Frank, J., King, A. R., Raine, D. J.: **Accretion Power in Astrophysics.** *2nd ed. Cambridge University Press, Cambridge, 1992.*

Gilmore, G., King, I., Kruit, van der, P. C.: **The Milky Way as a Galaxy.** *University Science Books, Lecture Notes, 1989.*

Griffiths, J. B., Podolský, J.: **Exact Space-Times in Einstein's General Relativity.** *Cambridge University Press, Cambridge, 2012.*

Hansen, C. J., Kawaler, S. D.: **Stellar Interiors: Physical Principles, Structure and Evolution.** *Springer–Verlag, New York, 1994.*

Hawking, S. W., Ellis, G. F. R.: **The Large Scale Structure of Space-Time.** *Cambridge University Press, Cambridge, 1973.*

Itzykson, C., Zuber, J.: **Quantum Field Theory.** *McGraw–Hill, New York, 1982.*

Kippenhahn, R., Weigert, A.: **Stellar Structure and Evolution.** *Springer–Verlag, Berlin, 1991.*

Mahan, G. D.: **Many–particle Physics.** *Plenum Press, New York, 1990.*

Martynov, D. J.: **Kurs Prakticeskoj astrofyziky.** *Nauka, Moskva.*

Mihalas, D.: **Stellar Atmospheres.** *W. H. Freeman & Co., San Francisco, 1978.*

Misner, C., Thorne, K. S., Wheeler, J.: **Gravitation.** *W. H. Freeman & Co., San Francisco, 1973.*

Plischke, M., Bergsen, B.: **Equilibrium Statistical Physics.** *2nd ed. World Scientific, Singapore, 1994.*

Reed, M., Simon, B.: **Methods of Modern Mathematical Physics.** *Academic Press, New York, 1979.*
Rickayzen, G.: **Green's Function and Condensed Matter.** *Academic Press, London, 1984.*
Rose, W. K.: **Advanced Stellar Astrophysics.** *Cambridge University Press, Cambridge, 1998.*
Schatzman, E. L., Praderie, F.: **The Stars.** *Astronomy and Astrophysics Library, Springer–Verlag, Berlin, 1993.*
Schwarzschild, M.: **Structure and Evolution of the Stars.** *Princeton University Press, Cambridge, 1958.*
Stephani, H., Kamer, D., MacCallum, M., Hoenselaers, C., Herlt, E.: **Exact Solutions of Einstein's Equations.** *Cambridge University Press, Cambridge, 2003.*
Sternberg, S.: **Group theory and physics.** *Cambridge University Press, Cambridge, 1994.*
Tanenbaum, B. S.: **Plasma Physics.** *McGraw–Hill, New York, 1967.*
Wald, R. M.: **General Relativity.** *University of Chicago Press, 1984.*
Walker, G. A. H.: **Astronomical Observations.** *Cambridge University Press, Cambridge, 1999.*
Weinberg, S.: **Quantum Theory of Fields I–III.** *Cambridge University Press, Cambridge, 1995–2000.*
Wheeler, J. A., Zurek, W. H., eds.: **Quantum Theory and Measurement.** *Princeton University Press, Princeton, 1983.*

Study programme P4F2A Physics of Plasmas and Ionized Media

Annotation

The study program covers all aspects of plasma physics and naturally follows to a broader master's degree in "Physics of surfaces and ionized media." Thanks to the focus of the field, which includes not only an extensive area of plasma physics, but also extends to theoretical physics (elementary processes) and some topics of astrophysics (plasma of interplanetary space, problems of dust / ice clusters in the solar system), it is also attractive for students who follow-up master's studies in these fields. The program is unique in Charles University thanks to a comprehensive view of plasma physics, including the experimental study of laboratory and cosmic, low-temperature and hot plasma, and often supported by numerical simulations.

Board of the doctoral programme

Members of the board: `http://mff.cuni.cz/phd/or/p4f2` .

Cooperating institutions

- Astronomical Institute, CAS
  Fričova 298, 251 65 Ondřejov

http://www.asu.cas.cz/

- Institute of Physics, CAS
  Na Slovance 2, 182 21 Praha 8
  http://www.fzu.cz/

- J. Heyrovsky Institute of Physical Chemistry, CAS
  Dolejškova 2155/3, 182 23 Praha 8
  http://www.jh-inst.cas.cz/

- Institute of Atmospheric Physics, CAS
  Boční II/1401, 141 31 Praha 4
  http://www.ufa.cas.cz/

- Institute of Plasma Physics, CAS
  Za Slovankou 1782/3, 182 00 Praha 8
  http://www.ipp.cas.cz/

Home page of the study programme

http://physics.mff.cuni.cz/kfpp/4F2/

Available topics of the dissertation

Topics are listed in SIS at http://mff.cuni.cz/phd/temata/p4f2

Applicants are advised to register in advance on the selected topics with an offer of extended financial support: https://www.mff.cuni.cz/en/physicsphd/f2/ . The pre-selected candidates will facilitate the passage through the admission procedure.

Available courses

Code	Subject	Winter	Summer
NEVF501	**Low Temperature Plasma and Its Applications**	2/0 Ex	—
NEVF502	**Elementary Processes in Plasma**	2/0 Ex	—
NEVF503	**Measurement Methods, Modelling and Processing of Experimental Data**	2/0 Ex	—
NEVF504	**Physical Processes in Solar System**	2/0 Ex	—
NEVF505	**Plasma Diagnostics**	2/0 Ex	—
NEVF506	**Magnetohydrodynamics, Hot and Laser Plasma**	2/0 Ex	—
NEVF518	**Introduction to Plasma Physics**	2/0 Ex	—
NEVF538	**Fusion Plasma**	2/0 Ex	—
NEVF507	**Seminar on Computation and Measuring Techniques**	—	0/2 C
NEVF508	**Seminar on Modern Trends in Physics**	—	0/2 C
NEVF536	**Course of Special Experimental Method in Plasmas and Chemical Physics**	—	2/0 C
NEVF537	**Selected Topics from Space Plasmas**	—	2/0 C

NEVF550	**Workshop**	0/2 C	—
NEVF555	**Student Conference**	—	0/3 C
NEVF135	*Programming in IDL — Data Processing and Visualisation*	1/1 MC	—
NEVF145	*Space Plasma*	—	2/1 C+Ex

Student chooses courses and further obligations from the offer of the study programme.

Requirements for the course of doctoral studies

a) 1st and 2nd year of study: in each year 1 joint extension course, 2 lectures according to the individual study plan in the agreement with topic of the dissertation.

b) 1st-4th year of study: in each year an attendance at professional seminar and active participation in a winter professional workshop.

c) Presentation at WDS (Week of Doctoral Students) every year of study. Publication in the WDS proceedings in the first 4 years of study (can be replaced by a publication in a journal). Review of a contribution to the WDS proceedings.

d) Active participation in an international conference.

e) The condition for passing the state doctoral exam is the completion in total of 4 lecture courses completed by the examination.

f) During the study, the student is expected to complete a several-month stay at a foreign research group. Alternatively, he/she can participate in summer/winter school concerning the field of the dissertation at the beginning of the study.

g) The condition for the defense and completion of the study is the publication of student's own results in two publications in international impact journals. In both publications, the student's contribution should be crucial.

The board of the programme will assess the compliance of the requirements individually.

Requirements for the doctoral exam

The state doctoral exam is synthetic in nature, i.e., 3 broader questions are asked out of the 7 thematic areas that correspond to the content of the course lectures organized by the board (it is taken into account what lectures the student attended).

1 Low-temperature plasma and its applications

Definition and types of plasma. Kinetic description of low-temperature plasma, discharge plasma and its application in plasma technology (polymerization, etching, formation of thin layers, etc.). Hydrodynamic description of the plasma. Elementary processes, collision types, collision cross-sections. Radiation in the plasma. Transport phenomena, conductivity, diffusion, and ambipolar diffusion. Plasma chemical reactions. Waves in plasma. Complex (dust) plasma, its meaning and applications.

2 Elementary processes in plasma

Introduction to physical chemistry (molecular structure, states, ions, etc.), collisional processes (ionization, excitation, deexcitation, chemical reactions, recombination, etc.), thermodynamics and statistical thermodynamics in terms of physical chemistry, reaction kinetics and dynamics, ion–molecular reactions, introduction to plasma chemistry and laser chemistry.

3 Methods of measurement, modelling, and processing of experimental data

Analogue and digital signals, analogue and digital noise (continuous and discrete random processes), digital filtering (overview of methodologies, types of filters, design of integration and derivative filters, smoothing methods, etc.), estimation of model parameters, errors of estimations. Optimal detection (statistical properties, implementation methods). Random processes, fluctuations, and noise. Correlation, frequency spectrum of the signal and its measurement.

4 Physical processes in the solar system

Basic concepts from magnetohydrodynamics, particle motion in fields, analytical solution of particle motion in adiabatic approach, Solar system, description of Earth–Sun relations, interplanetary magnetic field, plasma in interplanetary system, solar wind, shock waves, magnetopause and Earth's magnetosphere, particle transport in Earth's surroundings. The interaction of the solar wind with the magnetosphere, reconnection of magnetic fields. Waves in cosmic plasma.

5 Plasma diagnostics

Overview of diagnostic methods, optical methods, microwave measurement technique, resonator method, interference method, probe methods, particle diagnostics. Diagnostic methods used in outer space.

6 Magnetohydrodynamics, hot and laser plasmas

Magnetohydrodynamic approach, one and two-fluid model, frozen field and diffusion of force lines, magnetic energy and magnetic pressure, examples. Introduction to the physics of fusion. Fusion device principles: tokamak, stellerator, z-pinch, inertial retention. Processes of interaction of high laser radiation flows with plasma, characteristics and problems of theoretical description of high energy density systems, principles of X-ray laser, inertial fusion.

7 Nuclear fusion, tokamak

Fusion fundamentals, tokamak principle. Tokamak — magnetic topology, plasma stability, heating methods, influence of impurities. Edge plasma, its interaction with the wall, the formation of plasma. Turbulence and instabilities, methods of their suppression. Tokamak plasma simulation methods. Diagnostic methods in tokamaks (of both plasma and magnetic fields). Materials used in tokamaks, tokamak operation and control.

Recommended literature

Atkins, P. W.: **Physical Chemistry.** *Oxford University Press, Oxford, 1988.*

Baumjohann, W., Treumann, R. A.: **Basic Space Plasma Physics.** *Imperial College Press, London, 1999.*

Biskamp, D.: **Magnetohydrodynamic Turbulence.** *Cambridge University Press, Cambridge, 2003.*

Bonitz M., Horing N., Ludwig P.: **Introduction to Complex Plasmas.** *Springer 2010.*

Bertotti, B., Farinella, P., Vokrouhlický, D.: **Physics of the Solar System.** *Springer, Dordrecht 2003.*

Bittencourt, J. A.: **Fundamentals of Plasma Physics.** *Springer, New York, 2004.*

Cravens, T. E.: **Physics of Solar System Plasma.** *Atmospheric and Space Science Series, Cambridge University Press, Cambridge, 1998.*

Encrenaz, T. et al.: **The Solar System.** *Springer, Berlin–Heidelberg–New York, 2004.*

Fanning, D. W.: **IDL Programming Techniques.** *2nd ed. 2000.*

Freidberg, J. P.: **Plasma Physics and Fusion Energy.** Cambridge University Press, Cambridge 2007.¡/I¿

Ghosh, P. K.: **Ion Traps.** *Clarendon Press, Oxford, 1995.*

Glosík, J. (ed.): **Study texts for the course on Elementary processes in Plasma.** *MFF UK, Prague, 2020.*

Goldston, R. J., Rutherford, P. H.: **Introduction to Plasma Physics.** *Institute of Physics Publishing, Bristol–Philadelphia, 1995.*

Gombosi, T. I.: **Physics of the Space Environment.** *Atmospheric and Space Science Series, Cambridge University Press, Cambridge, 1998.*

Gross, R.: **An Introduction to Alfven Waves.** *The Adam Hilger Series on Plasma Physics, Bristol, 1988.*

Grün, E., Gustafson, B. A. S., Dermott, S., Fechtig, H.: **Interplanetary Dust.** *Astronomy and Astrophysics Library, Springer, Berlin, 2001.*

Hargreaves, J. K.: **The Solar–terrestrial Environment.** *Cambridge Atmospheric and Space Science Series, Cambridge University Press, Cambridge, 1992.*

Huddlestone, R. H., Leonard, S. L. (Eds.): **Plasma Diagnostic Techniques.** *Academic Press, New York, London 1965.*

Hutchinson, I. H.: **Principles of Plasma Diagnostics.** *Cambridge University Press, Cambridge, 2002.*

Chen, F. F.: **Plasma Diagnostic Techniques.** *Academic Press, New York, 1965.*

Chen, F. F.: **Introduction to Plasma Physics and Controlled Fusion.** *Third Edition. Springer, Cham, 2016.*

Chung, P. M., Talbot, L., Touryan, K. J.: **Electrical Probes in Stationary and Flowing Plasmas.** *Springer, Boston, 1975 (rusky: Mir, Moskva, 1978).*

Kallenrode, M. B.: **Space Physics: An Introduction to Plasma and Particles in the Heliosphere and Magnetospheres.** *Springer–Verlag, Berlin–Heidelberg, 2001.*

Kivelson, M. G., Russell, C. T.: **Introduction to Space Physics.** *Cambridge University Press, Cambridge, 1995.*

Kaufman, A. N., Cohen, B. I.: **LECTURE NOTES: Theoretical plasma physics.** *Journal of Plasma Physics, Volume 85 , Issue 6 , December 2019 , 205850601.*

Lautrup, B.: **Physics of Continuous Matter: Exotic and Everyday Phenomena in the Macroscopic World.** *Institute of Physics Publishing, Bristol and Philadelphia, 2005.*

Peratt, A. L.: **Physics of the Plasma Universe.** *Springer–Verlag, New York–Heidelberg, 1991.*

Pfaff, R. F., Borovsky, J. E., Young, D. T. (Eds.): **Measurement Techniques in Space Plasmas: Particles.** *AGU, Geophysical Monograph 102, Washington, DC, 1998.*

Pfaff, R. F., Borovsky, J. E., Young, D. T. (Eds.): **Measurement Techniques in Space Plasmas: Fields.** *AGU, Geophysical Monograph 103, Washington, DC, 1998.*

Piel, A.: **Plasma Physics, An Introduction to Laboratory, Space, and Fusion Plasmas.** *Springer-Verlag, Berlin-Heidelberg, 2010.*

Priest, E. R. (ed.): **Solar System Magnetic Fields.** *Terra Scient. Publ. Co., Tokyo, 1985.*

Shukla, P. K., Mamun, A. A.: **Introduction to Dusty Plasma Physics.** *Institute of Physics Publishing, Bristol and Philadelphia, 2002.*

Schott, L.: **Plasma Diagnostics.** *North–Holland Publishing Comp., Amsterdam, 1968.*

Song, P., Singer, H. J., Siscoe G. L. (Eds.): **Space Weather.** *AGU, Geophysical Monograph 125, Washington, DC. 2001.*

Svanberg, S.: **Atomic and Molecular Spectroscopy.** *Springer-Verlag Berlin Heidelberg New York 1992.*

Swamy, K.: **Dust in the Universe: Similarities and Differences.** *World Scientific Series in Astronomy and Astrophysics, World Scientific Publishing, Singapure, 2005.*

Thompson, M. J.: **An Introduction to Astrophysical Fluid Dynamics.** *Imperial College Press, London, 2006.*

Treumann, R. A., Baumjohann, W.: **Advanced Space Plasma Physics.** *Imperial College Press, London, 2001.*

Walker, A. D. M.: **Plasma Waves in the Magnetosphere.** *Springer Verlag, Berlin–Heidelberg, 1993.*

Werth, G., Gheorghe, V. N., Major, F. G.: **Charged Particle Traps.** *Springer Berlin Heidelberg New York 2005.*

Werth, G., Gheorghe, V. N., Major, F. G.: **Charged Particle Traps II.** *Springer-Verlag Berlin Heidelberg 2009.*

Wesson, J.: **Tokamaks** *Fourth Edition. Oxford University Press, 2011.*

Study programme P4F3A Physics of Condensed Matter and Materials Research

Annotation

The programme prepares specialists qualified for independent activity in basic and applied research in the field of physical properties of condensed matter and materials. The students gain broad knowledge of relevant theoretical approaches (quantum theory, thermodynamic and statistical physics) and of their employment in theoretical and experimental physics of condensed matter, and become familiar with up-to-date experimental methods and technological procedures. Beside the basic education common for the whole study programme, the student gain a deep knowledge according to the dissertation topic and to the choice of optional specialized courses. This pattern guarantees that the graduate has an overview of the whole field at the current level of the knowledge and is an expert in the chosen specialty.

Board of the doctoral programme

Members of the board: http://mff.cuni.cz/phd/or/p4f3 .

Cooperating institutes

- Institute of Physics, CAS
  Na Slovance 2, 182 21 Praha 8
  http://www.fzu.cz/

- Institute of Photonics and Electronics, CAS
  Chaberská 57, 182 51 Praha 8
  http://www.ufe.cz/

- Nuclear Physics Institute, CAS
  Husinec – Řež č. p. 130, PSČ 250 68
  http://www.ujf.cas.cz/

- Institute of Macromolecular Chemistry, CAS
  Heyrovského nám. 2, 162 06 Praha 6
  http://www.imc.cas.cz/

- Institute of Thermomechanics, CAS
  Dolejškova 1402/5, 182 00 Praha 8
  http://www.it.cas.cz/

Homepage of the board

http://krystal.karlov.mff.cuni.cz/f3

Available topics of the dissertation

Topics are listed in SIS at http://mff.cuni.cz/phd/temata/p4f3 .

Selected topics for the preliminary admission procedure

https://www.mff.cuni.cz/en/physicsphd/f3/ .

Courses and other requirements for the course of doctoral study

In agreement with the supervisor, the student enrolls the compulsory lecture courses of the corresponding Master's programme if he/she has not completed these or analogous courses during his/her Master study.

During the doctoral study, the student passes the compulsory courses and according the topic of his/her dissertation chooses the elective courses and eventually other optional courses according the recommendation of his/her supervisor. He/she participates in regular seminars.

Compulsory courses

Code	Subject	Winter	Summer
NBCM083	**Selected Topics on Quantum Theory**	2/1 C+Ex	—

NFPL088	**Methods of Statistical Physics**	2/1 C+Ex	—
NFPL085	**Electronic Theory of Solids**	—	2/0 Ex
NFPL087	**Seminar on Solving Physical Problems**	—	0/2 C
NFPL086	**Experimental Methods in Condensed Matter Physics**	2/2 Ex	—

Elective courses

Code	Subject	Winter	Summer
NFPL082	*Magnetism and Electronic Structure of Metallic Systems*	2/0 Ex	—
NFPL120	*Modern Problems in Physics of Materials*	2/0 Ex	—
NFPL063	*Advanced Quantum Theory with Applications in Condensed Matter Physics*	—	2/1 Ex
NFPL093	*Selected Topics on Magnetic Resonance Theory and Methodology*	2/0 Ex	—
NFPL128	*Selected Topics on Positron Annihilation Spectroscopy*	—	1/1 C+Ex
NFPL178	*Superfluidity and Bose-Einstein Condensation*	—	2/1 C+Ex
NFPL195	*Selected Topics on Low Temperature Physics*	—	2/0 Ex
NFPL066	*Advanced Methods and Contemporary Topics on Structure Analysis*	2/0 C	—

Requirements for the course of doctoral studies

1) A pre-requisite for the enrollment for the doctoral exam is a completion of all compulsory courses listed in the table, one course from the table of elective courses, and participation in two seminars (two times one semester). The student is also obliged to give a lecture at WDS (Week of Doctoral Students).

2) The student regularly attends other seminars (in total number of 4 semesters during the study) and under the circumstances, he/she attends a suitable summer or winter school.

3) According the supervisor advice, the student can enroll for other proper elective or optional courses.

4) During all the study, the student works intensively on a solution of the dissertation tasks, presents his/her results at seminars and scientific conferences and participates in preparation of scientific publications. According to the directions of the supervisor, the student is involved in an international cooperation.

Requirements for the doctoral exam

Wider focused questions are asked with the aim to test the ability of the student to be oriented in the given issue. The exam consists of three parts: I — Broader background, II — Advanced parts of the field, III — Specialization. The student is asked one question from each part.

I. Broader background

I.1. Quantum-mechanical description of atoms and condensed matter
I.2. Many-particle systems

I.3. Electronic states in atom and condensed matter
I.4. Interaction of quantum system with electromagnetic radiation
I.5. Classical and quantum statistical ensembles
I.6. Thermodynamic quantities
I.7. Ideal, classical, and quantum gases
I.8. Fermions and bosons at low temperatures
I.9. Phase transitions
I.10. Non-equilibrium processes in condensed matter

II. . Advanced parts

II.1. Structure and microstructure of condensed systems
II.2. Phonons
II.3. Electronic and atomic structure and interactions in condensed systems
II.4. Metals and semiconductors
II.5. Dielectrics and ferroelectrics
II.6. Magnetism
II.7. Physics of condensed systems at low temperatures, superconductivity, superfluidity

III. Specialization

Questions from the subject of the specialization will be proposed by the supervisor. The Commission selects one of at least three issues proposed.

Recommended literature

Abragam, A.: **Principles of Nuclear Magnetism.** *Clarendon Press, 1983.*

Ashcroft, N. W., Mermin, N. D.: **Solid State Physics.** *Sounders Coll. Publishing, Philadelphia, 1988.*

Barbara, B., Gignoux, D., Vettier, C.: **Lectures on Modern Magnetism.** *Springer–Verlag, Berlin, 1988.*

Buschow, K. H. J., Cahn, R. W., Flemings, M. C., Ilschner, B., Kramer, E. J., Mahajan, S.: **The Encyclopedia of Materials: Science and Technology.** *Pergamon Press, Oxford, 2001.*

Cahn, E. W., Lifshin, E.: **Concise Encyclopedia of Materials Characterization.** *Pergamon Press, Oxford, 1993.*

Giacovazzo G. et al.: **Fundamentals of Crystallography**, 2nd ed., *IUCr, Oxford Science Publications, Oxford 2002.*

Ibach, H., Luth, H.: **Solid–State Physics.** *Springer–Verlag, Berlin, 1991.*

Kittel, C.: **Introduction to Solid State Physics**, 8th ed. *John WileySons, 2005.*

F.Pobell, F.: **Matter and Methods at Low Temperatures**, *2007.* ISBN 978-3-540-46360-3

Reed R.C.: **The Superalloys Fundamentals and Applications**, *Cambridge, UK, 2006.*

Slichter, C. P.: **Principles of Magnetic Resonance.** *Springer Series in Solid-State Sciences book series (SSSOL, volume 1), 3rd edition, 1989.*

Smallman, R.E., Bishop, R.J.: **Modern Physical Metallurgy**, *Butterworth-Heinemann, Oxford, UK, 1999.*

Tilley, D.R., Tilley, J.: **Superfluidity and Superconductivity**, 3rd ed., *IoP Publishing, 1990.*
Ziman, J. M.: **Principles of the Theory of Solids.** *Cambridge University Press, Cambridge, 1965.*

Study programme P4F4A Biophysics, Chemical and Macromolecular Physics

Annotation

The study programme follows the Master's program "Biophysics and Chemical Physics" and the specialization "Physics of Macromolecular Substances" of the Master's programme "Physics of Condensed Matter and Materials". Its aim is education in an interdisciplinary area at interface of physics, chemistry and biology from the position of physical description and in physical experimental and theoretical approaches; thereby its a unique within CU study programmes. Graduates are successful in both basic and applied research in fields of Biophysics, Biochemistry, Physical Chemistry and Chemical Physics, Macromolecular Physics and Chemistry, Microbiology, Physiology and Biological Medical research.

Board of the doctoral programme

Members of the board: `http://mff.cuni.cz/phd/or/p4f4` .

Cooperating institutes

- Institute of Physics, CAS
  Na Slovance 2, 182 21 Praha 8
  `http://www.fzu.cz/`

- Institute of Physiology, CAS
  Vídeňská 1083, 142 20 Praha 4
  `https://www.fgu.cas.cz/`

- Institute of Microbiology, CAS
  Vídeňská 1083, 142 20 Praha 4 - Krč
  `https://mbucas.cz/`

- Institute of Photonics and Electronics, CAS
  Chaberská 57, 182 51 Praha 8
  `http://www.ufe.cz/`

- J. Heyrovsky Institute of Physical Chemistry, CAS
  Dolejškova 2155/3, 182 23 Praha 8
  `http://www.jh-inst.cas.cz/`

- Institute of Macromolecular Chemistry, CAS
  Heyrovského nám. 2, 162 06 Praha 6
  http://www.imc.cas.cz/

- Institute of Organic Chemistry and Biochemistry, CAS
  Flemingovo nám. 2, 166 10 Praha 6
  http://www.uochb.cas.cz/

Available topics of the dissertation

Topics are listed in SIS at http://mff.cuni.cz/phd/temata/p4f4 .

Selected topics for the preliminary admission procedure

https://www.mff.cuni.cz/en/physicsphd/f4/ .

Homepage of the board

http://biomolecules.mff.cuni.cz/4F4

Available courses

Code	Subject	Winter	Summer
NBCM012	**Biochemistry**	—	3/0 Ex
NBCM023	**Importance and Functions of Metal Ions in Biological Systems**	2/0 Ex	—
NBCM039	**Quantum Theory of Molecules**	3/2 C+Ex	—
NBCM041	**Fundamentals of Energy Transfer in Molecular Systems I**	2/0 Ex	—
NBCM046	**Seminar on Theoretical Chemical Physics**	0/1 C	0/1 C
NBCM055	**Molecular Simulations for solving of material structure**	2/1 C+Ex	2/1 C+Ex
NBCM058	**Relaxation Behaviour of Polymers**	—	2/0 Ex
NBCM059	**Application of Low Temperature Plasma**	2/0 Ex	—
NBCM066	**Introduction to Macromolecular Chemistry**	2/1 C+Ex	—
NBCM076	**Theory of Polymer Structures**	2/0 Ex	—
NBCM091	**Seminar on Polymer Physics**	0/2 C	0/2 C
NBCM097	**Surface-Enhanced Raman Spectroscopy**	—	2/0 Ex
NBCM098	**X-ray and Electron Structure Analysis of Biomolecules and Macromolecules**	2/0 Ex	—
NBCM127	**Biophysical Methods in Photosynthesis Studies**	—	2/0 Ex
NBCM128	**Advanced Methods in Molecular Spectroscopy**	—	2/0 Ex
NBCM129	**Experimental Technology in Optical Spectroscopy and Radiometry**	—	2/0 Ex
NBCM130	**Seminar on Optical Spectroscopy**	—	0/2 C

NBCM200	**Seminar on Plasma Polymer Studies**	0/2 C	0/2 C
NBCM208	**Fundamentals of Macromolecular Physics**	—	3/0 Ex
NBCM228	**Polymers for Applications in Photonics and Optoelectronics**	2/0 Ex	—
NBCM300	**Seminar for Ph.D. Students — Structure and Spectroscopy of Biomolecules**	0/2 C	0/2 C
NBCM301	**Seminar for Ph.D. Students — Contemporary Problems in Molecular Biology**	0/2 C	0/2 C
NBCM305	**Optical Sensors**	2/0 Ex	—
NBCM316	**Computer Modelling of Biomolecules**	1/2 C+Ex	1/2 C+Ex
NBCM317	**Advanced Molecular Spectroscopy**	1/1 C+Ex	—
NFPL179	**Quantum Description of NMR**	—	2/1 C+Ex
NFPL186	**Seminar on High Resolution NMR Spectroscopy**	0/2 C	0/2 C
NOOE119	**Nonlinear Optical Spectroscopy**	—	2/0 Ex

Requirements for the course of doctoral studies

a) The lecture courses should be passed during the first and the second year of the studies. In agreement with the supervisor, the student enrolls for courses that are coherent with the dissertation topic and for those extending his/her general knowledge in respect to the reguirements for the doctoral exam. Beside the above-mentioned courses, students may choose from the whole offer of courses provided by CU, in the reasoned cases also courses at other universities.

b) The student is obliged to give a presentation at the Week of Doctoral Students before the end of the second (the third in the case of the doctoral study starting in the spring date) semester. He/she also participates in a regular seminar organized by the department and/or the research group.

c) It is recommended to pass the doctoral exam at the end of the second year of the study. A pre-requisite for the enrollment for the doctoral exam is a completion by a successful exam of at least three lecture courses.

d) The involvement of the student in an international cooperation via stays in foreign research groups and/or attending summer/winter schools and international scientific conferences is highly desirable.

d) For the defense of the dissertation, it is required that its results are published in international scientific journals. The extend and quality of publications should correspond to the level of two papers in impacted journals (WOS) with the main contribution of the student.

Requirements for the doctoral exam

The exam consists of 3 questions, two of which concern two thematic areas chosen by the student and one in focused to the field of the dissertation topic. The latter is usually formulated by the supervisor in a respect to the study plan. According to the student's responses, additional questions concerning the general physical terms and relations may be asked at the level corresponding to the final exam in the Bachelor study programme "Physics" and the requirements for the final exams in the Master's study programme "Biophysics and Chemical Physics" and/or in the Master's study programme "Physics of Condensed Matter and Materials" - specialization "Physics of Macromolecular Substances".

Thematic area 1. Quantum theory and statistical physiscs of molecular systems

Basic methods of quantum-chemical calculations of molecules. Atomic and molecular orbitals. π–electron approximation and Hückel method. Hartree–Fock equations and Roothaan equations. Electron correlation, correlation energy. Configuration interaction. Bound clusters and perturbation methods of correlation energy calculation.Density functional methods. Calculations of weak intermolecular interactions. Vibrational molecular states. Methods of electronic spectra calculations. Thermodynamic potentials. Thermodynamic laws. Statistical ensembles, basic statistical distributions. Basic laws of equilibrium and non-equilibrium physics. Liouville equation, Boltzmann equation, Pauli kinetic equation, generalized master equations. Molecular simulations, empiric potentials, Monte Carlo methods, molecular dynamics. Chemical kinetics. Electrochemistry.

Thematic area 2. Physics and chemistry of molecular structures

Forces determining molecular structural arrangement, conformations, phase states and transitions in molecular systems (solutions, polymers, molekular and liquid crystals, thin layers, biopolymers and membrane systems). Physics and chemistry of proteins and nucleic acids (chemical composition, 3D structute, formation of complexes, biological function). Cell composition and main intracellular processes. Phorophysics and transport phenomena in polymers.

Thematic area 3. Experimental methods

Interaction of electromagnetic field with molecular and biological structures (width and shape of spectral bands, relaxation processes). Structural determination of molecular and biological systems (X-ray and neutron diffraction, electron microscopy). Application og magnetic resonance (ESR, NMR, spin probes and markers, echo methods, structure determination by 2D methods). Methods of elastic and dynamic light scattering for determinantion of the structure and motion of molecular objects. Employment of optical spectroscopy in study of the structure, interactions, and dynamics of the energy and charge transport in molecular and biological systems (vibrational IR spektroscopy, UV – VIS absorption and emission spectroscopy, methods of high time and spectral resolution, polarization phenomena, optical chiroptic methods, Raman scattering, non-linear optical methods). Application of electric and dielectric methods.

Basic reccomended literature

Blankenship, R. E.: **Molecular Mechanisms of Photosynthesis.** *Blackwell Science, Oxford, 2002.*

Cantor, C. R., Schimmel, P. R.: **Biophysical Chemistry, vol. I, II, III.** *W. H. Freeman & Co., San Francisco, 1980 (rusky: Biofizičeskaja chimija. Mir, Moskva, 1984).*

Cavanagh J. et al.: **Protein NMR Spectroscopy: Principles and Practice.** *2nd edition, Elsevier Academic Press 2007*

Davydov, A. S.: **Kvantová mechanika.** *SPN, Praha, 1978.*

Demtröder, W.: **Laser Spectroscopy.** *Springer, Berlin, 2005.*

Guillet, J.: **Polymer Photophysics and Photochemistry.** *Cambridge University Press, Cambridge, 1985 (rusky: Fotofizika i fotochimija polimerov. Mir, Moskva, 1988).*

Kao, K. C., Hwang, W.: **Electrical Transport In Solids, vol. 1,2.** *Pergamon Press, Oxford, 1981 (rusky: Perenos elektronov v tverdych telach. Mir, Moskva, 1984).*

Klíma, J., Šimurda, M.: **Sbírka problémů z kvantové teorie.** *Academia, Praha, 2006.*

Prosser, V. a kol.: **Experimentální metody biofyziky.** *Academia, Praha, 1989.*

Skála, L.: **Kvantová teorie molekul.** *Karolinum, Praha, 1995.*

Skála, L.: **Úvod do kvantové mechaniky.** *Academia, Praha, 2005.*

Sperling, L. H.: **Introduction to Physical Polymer Science.** *Wiley, New York, 1986.*

Study programme P4F5A Physics of Surfaces and Interfaces

Annotation

The program naturally follows up on the field of master's studies "Surface and Plasma Physics", but it can also follow on from another master's degree in solid state physics. The study program covers all aspects of physics of surfaces and thin films. It is leaning on knowledge of physical and chemical properties of solid surfaces and interfaces and related physical processes. The study includes problems of basic research in material science and nanophysics, study of surface structures and processes at atomic level, surface catalysis as well as frontier disciplines such as fuel cell technology. The experimental approach is closely related to the theoretical study of the problem. Program prepares experts with a broad foundation in physics, with rich experience in advanced surface experimental techniques and with deep knowledge of surface physics and chemistry.

Board of the doctoral programme

Members of the board: `http://mff.cuni.cz/phd/or/p4f5` .

Cooperating institutes

- Institute of Physics, CAS
  Na Slovance 2, 182 21 Praha 8
  `http://www.fzu.cz/`

- Institute of Photonics and Electronics, CAS
  Chaberská 57, 182 51 Praha 8
  `http://www.ufe.cz/`

- J. Heyrovsky Institute of Physical Chemistry, CAS
  Dolejškova 2155/3, 182 23 Praha 8
  `http://www.jh-inst.cas.cz/`

Homepage of the study programme

http://physics.mff.cuni.cz/kfpp/f5/

Available topics of the dissertation

Topics are listed in SIS at http://mff.cuni.cz/phd/temata/p4f5 .

Selected topics for the preliminary admission procedure

https://www.mff.cuni.cz/en/physicsphd/f5/ .

Available courses

Code	Subject	Winter	Summer
NEVF514	**Physics of Surfaces**	2/0 Ex	—
NEVF515	**Methods of Physics of Surfaces and Thin Films I**	—	2/0 Ex
NEVF516	**Methods of Physics of Surfaces and Thin Films II**	2/0 Ex	—
NEVF517	**Seminar on Physics of Surfaces and Thin Films**	—	0/2 C
NEVF550	**Workshop**	0/2 C	—
NEVF555	**Student Conference**	—	0/3 C

Requirements for the course of doctoral study

a) Study duties

1.-2. year: completion of compulsory lectures

1.-4. year: Seminar on Physics of Surfaces and Thin Films

Compulsory lectures: Physics of Surfaces NEVF 514, Methods of Physics of Surfaces and Thin Films I NEVF 515, Methods of Physics of Surfaces and Thin Films II NEVF 516, Seminar on Physics of Surfaces and Thin Films NEVF 517.

In addition to compulsory lectures, the student enrolls in the individual study plan the lectures recommended by the supervisor according to the topic of the dissertation.

b) Requirements for creative activity:

-research work on the topic of the dissertation

-presentation at WDS (Week of Doctoral Studies) in the 1st or 2nd year of study

-presentation of results at the KFPP winter camp during full-time study

-at least one first authorship on a publication on the topic of the dissertation in an impact journal

c) Requirements for completing internships

In accordance with the standards of study programs at Charles University, part of the study obligations in the doctoral SP is the completion of part of the study at a foreign institution for a total of at least one month or another form of direct student participation in international cooperation. Another internship abroad is desirable, but not a condition.

d) Additional study duties

-participation at a suitable winter or summer school or conference

-English language exam

The board of the programme will assess the compliance of the requirements individually.

Requirements for the state doctoral exam

I. General basis

Electromagnetic field. Photons. Wave function. Uncertainty relation. Schrödinger equation and its solution in simple cases. Approximate methods of quantum theory. Electron in a periodic field, band structure. Chemical bond. Thermodynamic potentials, equilibrium, phase rule, phase transitions. Statistical distributions, relation of thermodynamic and statistical quantities, entropy. Random processes, fluctuations, their characteristics. Crystallography and structure of solids, types of bonds. Electronic structure of solids, types of bonds. Transport phenomena, continuity equations, diffusion equations, relaxation times, scattering mechanisms. Phonons.

II. Physical foundations of the field

Volume and surface processes in vacuum systems, evaporation and condensation, interaction of gas with solid (surface, volume), pumping process, limit pressure. Physical principles of methods for obtaining and measuring of low pressures. Movement of charged particles in electric and magnetic fields, basic electron ion optical systems. Mass spectroscopy. Interfaces of two solids (metal-metal, metal-semiconductor, semiconductor-semiconductor), electronic processes at interfaces, physical principles and functions of electronic components. Solid surface (structure, purity, phenomena of reconstruction and relaxation), electronic surface structure (metals and semiconductors), surface conditions, band bending, work function. Physical phenomena at surfaces (adsorption, emission of charged particles - thermoemission, thermionic emission, surface ionization, tunnel emission, ionization in a strong field, photoemission; interaction of radiation and particles with a solid). Thin film growth theory, epitaxy. Properties of thin films, transport in thin films.

III. Experimental methods of physics of surfaces, thin films and interfaces

Formation of defined surfaces and thin films, basic methods and techniques. Methods of analysis of surfaces, thin films and interfaces (microscopy - TEM, SEM, FEM, FIM, STM, AFM, electron and ion spectroscopy - AES, XPS, APS, ..., diffraction methods - LEED, RHEED, X-ray).

Recommended literature

Bechstedt, F.: **Principles of Surface Physics.** *Springer–Verlag, Berlin, 2003.*

Bello, I.: **Vacuum and Ultravacuum Physics and Technology.** *CRC Press Taylor Francis Group, 2018.*

Chen, C.J.: **Introduction to scanning tunneling microscopy.** *Oxford University Press, 2008.*

Eckertová, L.: **Physics of thin films.** *SPN – Plenum Press, New York – Praha, 1986.*

Horn, K., Scheffler, M. (eds.): **Handbook of Surface Science Vol. II, Electronic structure.** *Elsevier, Amsterdam, 2000.*

Foster, A.S., Hofer, W.A.: **Scanning Probe Microscopy.** *Springer-Verlag, Berlin, 2006.*

Hufner, S.: **Photoelectron Spectroscopy, Principles and Aplications.** *Springer Verlag, 2003.*
Hummel, R.E.: **Electronic properties of materials.** *Springer, 1992.*
Ibach, H., Lueth, H.: **Solid state physics.** *Springer 2003.*
Jousten, K. (ed.): **Handbook of Vacuum Technology.** *Wiley-VCH Verlag, 2016.*
Kittel, Ch.: **Introduction to Solid State Physics.** *Wiley, New York, 2005.*
Michely T., Krug. J.: **Islands, Mounds and Atoms.** *Springer-Verlag Berlin Heidelberg, 2004.*
Lüth, H.: **Solid surfaces, Interfaces and thin films.** *Springer, Berlin, 2010.*
Reimer, L.: **Scanning Electron Microscopy Physics of Image Formation and Microanalysis.** *Springer-Verlag Berlin Heidelberg, 1998.*
Reimer, L., Khol, H.: **Transmission Electron Microscopy Physics of Image Formation.** *Springer-Verlag Berlin Heidelberg, 2008.*
Van Hove, M.A., Weinberg, W.H., Chan, C.M.: **Low-Energy Electron Diffraction: Experiment, Theory and Surface Structure Determination.** (Springer Series in Surface Sciences, Vol. 6) *Springer, Berlin, 1986.*
Venables, J. A.: **Introduction to Surfaces and Thin Film Processes.** *Cambridge University Press 2000.*
Voightlaender, B.: **Scanning Probe Microscopy.** *Springer-Verlag Berlin Heidelberg, 2015.*
Yu, P.Y., Cardona, M.: **Fundamentals of Semiconductors.** *Springer-Verlag, Berlin, 1999.*
Zangwill, A.: **Physics at surfaces.** *Cambridge University Press, Cambridge, 1988.*

Study programme P4F6A Quantum Optics and Optoelectronics

Annotation

The programme Quantum Optics and Optoelectronics offers individually guided study in which students gain extensive knowledge and skills for future independent scientific and research work in the field. According to the individual study plan, they focus on the area of their dissertation. The topics are closely connected with the scientific work of the supervisors who are active, e.g., in the fields of femtosecond laser spectroscopy, opto-spintronics, light detection, semiconductor optolectronics, terahertz spectroscopy, and laser physics.

Board of the doctoral programme

Members of the board `http://mff.cuni.cz/phd/or/p4f6` .

Cooperating institutes

- Institute of Physics, CAS
  Na Slovance 2, 182 21 Praha 8

http://www.fzu.cz/

- Institute of Photonics and Electronics, CAS
  Chaberská 57, 182 51 Praha 8
  http://www.ufe.cz/

Homepage of the board

http://physics.mff.cuni.cz/kchfo/ooe/4F6.htm

Available topics of the dissertation

Topics are listed in SIS at http://mff.cuni.cz/phd/temata/p4f6 .

Selected topics for the preliminary admission procedure

https://www.mff.cuni.cz/en/physicsphd/f6/ .

Courses

Compulsory courses:

Code	Subject	Winter	Summer
NOOE100	**Seminar on Quantum Optics and Optoelectronics for Ph.D. Students**	0/2 C	0/2 C

Elective courses (their extent has to correspond to at least 15 credits from lectures during the first three semesters of study): the student together with his/her supervisor selects lectures from the list of lectures provided by the Faculty of Mathematics and Physics, in accordance with the topic of the dissertation and requirements for the state examination.

Requirements for the state doctoral exam

I. Broader Backqround

Fundamental concepts and laws of classical and quantum physics. Macroscopic and microscopic description of physical phenomena. Symmetry and its role in physics. Fundamental concepts and laws of equilibrium and nonequilibrium statistical physics. Basics of nonlinear physics. Optical experiments of fundamental importance in physics.

II. Advanced topics

II.1. Wave and Quantum Optics

Methods of optical field description (approximation of ray, wave and quantum optics). Gaussian beams. Fourier optics. Optical coherence. Interference of light. Basics of holography. Diffraction of light. Guided waves and optical waveguides. Response of quantum systém to optical field. Linear and nonlinear optics. Electromagnetic field quantization. Light-matter interaction: emission, absorption, scattering-semiclasical and quantum description. Coherence and statistical properties of optical fields (nonclassical states of the optical fields). Optical experiments in quantum optics.

II.2. Laser Physics

Laser generators and amplifiers. Optical resonators. Laser modes. Laser types according to operational regime and active material. Classical, semiclassical and quantum description of laser, solution of laser equations. Dynamical properties of laser.

Laser systems with extreme output parameters. Interaction of laser radiation with matter, nonlinear optical phenomena. Nonlinear optical systems for efficient frequency transformation of laser beams. Laser spectroscopy.

II.3. Optoelectronics

Band theory of solids. Brillouin zone. Bloch function. Density of states. Quasiparticles in solids. Optical transitions. Semiconductor nanostructures. Conductivity, Boltzmann equation, scattering mechanisms, Hall effect, magnetoresistance. Quantum Hall effect. Photoconductivity, photoluminescence. Semiconductor detectors. Light emitting diodes, semiconductor lasers. Optical modulators. Heterostructures. Integrated optics. Metamaterials. Photonic crystals. Plasmonics. Basics of semiconductor technology.

III. Special part

One of the three questions, which is proposed in advance by the supervisor according to the student's narrower focus, is asked. Part of this section is also a discussion of dissertation theses, which the student submits in writing in the range of several pages.

Recommended literature

Bachor, H.-A., Ralph, T. C.: **A Guide to Experiments in Quantum Optics.** *Wiley-VCH, Weinheim, 2004.*

Born, M., Wolf, E.: **Principles of Optics**, 7th ed.*Cambridge University Press, Cambridge, 2019.*

Boyd, R. W.: **Nonlinear Optics.** *Academic Press, San Diego, USA, 1992.*

Davis, J. H.: **The Physics of Low–Dimensional Semiconductors.** *Cambridge University Press, Cambridge, 2000.*

Gerry, C.C. and Knight, P.L.: **Introductory Quantum Optics.** *Cambridge University Press, Cambridge, 2005.*

Haken, H.: **Light, vol. 1, 2.** *North–Holland, Amsterdam, 1981/5.*

Cheo, P. K.: **Fiber Optics and Optoelectronics.** *Prentice Hall, Englewood Cliffs, New York, 1985.*

Kittel, C.: **Introduction to Solid State Physics** , 8th ed. *John Wiley Sons, New York, 2004.*

Klingshirn, C. F.: **Semiconductor Optics.** *Springer–Verlag, Berlin, 2012.*

Loudon, R.: **The Quantum Theory of Light.** *Oxford University Press, Oxford, 2000.*

Mandel, L., Wolf, E.: **Optical Coherence and Quantum Optics.** *Cambridge University Press, Cambridge, 1995.*

Pelant I., Valenta J.: **Luminescence Spectroscopy of Semiconductors.** *OUP Oxford, 2012.*

Peřina, J.: **Quantum Statistics of Linear and Nonlinear Optical Phenomena.** *Reidel, Dodrecht, 1991.*

Peyghambarian N., Koch S. W., Mysyrowicz A.: **Introduction to Semiconductor Optics.** *Prentice Hall, Englewood Cliffs, 1993.*

Saleh, B. E. A., Teich, M. C.: **Fundamentals of Photonics** , 2nd edition. *John Wiley Sons, New York, 2006.*

Seeger, K.: **Semiconductor Physics.** *Springer–Verlag, Berlin, 2004.*

Svelto, O.: **Principles of Lasers** , 5th ed. *Plenum, Springer, Heidelberg, 2010.*

Study programme P4F7A Physics of the Earth and Planets

Annotation

The programme provides advanced theoretical knowledge of the physics of the Earth and planetary bodies and trains students in theoretical and numerical solutions of the forward and inverse problems. It includes earthquake physics, seismic waves propagation, studies of thermal evolution and deformation and of the gravity and magnetic fields of the Earth and planetary bodies. The graduate is able to carry out independent scientific research focused on the physical processes in the Earth, planets and satellites. He/she can pursue career in the research institutions focused on Earth and planetary evolution, but also in the industrial research focused on the issues of continuum mechanics.

Board of the doctoral programme

Members of the board: `http://mff.cuni.cz/phd/or/p4f7` .

Cooperating institutes

- Institute of Geophysics, CAS
  Boční II/1401, 141 31 Praha 4 - Spořilov
  `http://www.ig.cas.cz/`

- Institute of Rock Structure and Mechanics, CAS
  V Holešovičkách 41, 182 09, Praha 8
  `http://www.irsm.cas.cz/`

Available topics of the dissertation

Topics are listed in SIS at `http://mff.cuni.cz/phd/temata/p4f7` .

Selected topics for the preliminary admission procedure

`https://www.mff.cuni.cz/en/physicsphd/f7/` .

Courses

The student chooses from advanced Master's and doctoral lectures, especially among the following courses:

Code	Subject	Winter	Summer
NGEO111	**Continuum Mechanics**	—	2/1 C+Ex
NGEO069	**Continuum Mechanics II**	2/2 C+Ex	—
NGEO112	**Fourier Spectral Analysis**	—	2/1 C+Ex
NGEO110	**Review of Geophysics**	2/1 C+Ex	—
NGEO017	**Gravity field of the Earth and planets**	2/1 C+Ex	—
NGEO082	**Seismology**	2/1 C+Ex	—
NGEO074	**Earthquake source physics**	—	2/1 C+Ex

NGEO080	**Geomagnetism and Geoelectricity**	3/1 C+Ex	—
NGEO061	**Electromagnetic induction and conductivity of the Earth**	—	2/1 C+Ex
NGEO022	**Numerical Methods in Fortran**	—	3/1 C+Ex
NGEO002	**Seismic Waves Propagation**	2/1 C+Ex	—
NGEO057	**Methods of Geophysical Data Processing**	—	2/1 C+Ex
NGEO035	**Dynamics of Mantle and Lithosphere**	2/2 C+Ex	—
NGEO076	**Inverse Problems and Modelling in Physics**	—	2/0 Ex
NGEO081	**Inverse Problems and Modelling in Geophysics**	—	2/2 C+Ex
NGEO016	**Structure of the Earth**	3/0 Ex	—
NGEO084	**Seminar on Geodynamics**	0/2 C	0/2 C
NGEO083	**Seminar on Seismology**	0/3 C	0/3 C
NGEO032	**Ray Methods in Seismology**	2/1 C+Ex	—
NGEO108	**Planetary surface processes and tectonics**	2/0 Ex	—
NDGF015	**Mantle and Lithosphere Dynamics for Ph.D. Students**	2/0 Ex	2/0 Ex
NDGF014	**Geomagnetism and Geoelectricity for Ph.D. Students**	—	2/1 C+Ex
NDGF013	**Continuum Mechanics for Ph.D. Students**	—	2/0 Ex
NDGF018	**Boundary Value Problems of Physical Geodesy for Ph.D. Students**	2/0 Ex	2/0 Ex
NDGF012	**Earth Rotation for Ph.D. Students**	2/0 Ex	2/0 Ex
NDGF016	**Seismology for Ph.D. Students**	—	2/1 C+Ex

Requirements for the course of doctoral study

a) In the first year students should attend 1-3 courses according to their individual study plan. In the first or second year, they give presentation at the Week of Doctoral Students, Doctoral day or international conference. They should attend and present their results at department seminars during the course of study.

b) Before defending the thesis its results must be published in at least two papers in international journals with impact factor.

c) During PhD studies students should participate in international collaboration. Preferably by visiting foreign scientific institution (stay should be at least one month), but some other forms of international cooperation may be considered if necessary.

Requirements for the state doctoral exam

Doctoral exam has three parts. First question is focused on the topic of doctoral thesis. Second question is from obligatory part including fundamentals of geophysics and structure of the Earth (see part 1 below) and third question is from optional subject (see part 2 below).

1. Obligatory part

1.1 Fundamentals of geophysics

Earth motion. Gravity field, gravity measurements. Earth tides. Basic characteristics of earthquakes. Earth seismicity. Propagation of seismic waves. Earth magnetic field, internal and external field, variations. Paleomagnetism. Heat sources and heat propagation in the Earth interior. Convection in the Earth mantle. Age of the Earth. Inverse problem theory.

1.2 Structure of the Earth

Free oscillations of the Earth. Seismic reference model. Distribution of temperature, electric conductivity and viscosity in the Earth interior. Phase transitions. Global seismic tomographic models. Continental drift, plate tectonics.

2. Optional part

Student will choose one of the following blocks:

2.1 Seismology

Types of earthquakes and their distribution in the Earth body, seismicity. Macroseismic intensity, magnitude and energy of the earthquake. Earthquake source models. Theory of the seismic waves propagation. Seismic hazard. Seismic instruments, registration of seismic waves. Structural seismology.

2.2 Geodynamics

Energy balance of the Earth. Rheology of the mantle and lithosphere. Continuum mechanics, conservation of mass, momentum and energy. Numerical models of mantle convection. Subduction of lithospheric plates. Postglacial rebound. Dynamic geoid.

2.3 Geomagnetism and geoelectricity

Characteristics of electromagnetic field and its time variations. Models of electric conductivity in the crust and mantle. Dynamo theory of the geomagnetic field origin. Physics of ionosphere and magnetosphere.

2.4 Planetology

Representation of functions by spherical harmonic expansions. Determination of internal structure of planetary bodies. Relations between the shape of planetary body and its internal processes. Surface temperature, heat sources and propagation, tidal heating. Determination of surface age. Evolution of Solar system. Internal structure and thermal evolution of planets and moons.

Recommended literature

Aki, P. K., Richards, P.: **Quantitative Seismology.** *University Science Books, Sausalito, 2002.*

Brokešová, J.: **Asymptotic Ray Method in Seismology. A Tutorial.** *Matfyz Press, Praha, 2008.*

Červený, V.: **Seismic Ray Theory.** *Cambridge University Press, Cambridge, 2001.*

Dahlen, F. A., Tromp, J.: **Theoretical Global Seismology.** *Princeton University Press, Princeton, 1998.*

Fowler, C. M. R.: **The Solid Earth.** *Cambridge University Press, Cambridge, 1990.*

Lay, T., Wallace, T. C.: **Modern Global Seismology.** *Academic Press, New York, 1995.*

Martinec, Z.: **Principles of Continuum Mechanics.** *Birkhauser, Springer Nature, 2019.*

Merrill, R. T., McElhinny, M. W., McFadden, P. L.: **The Magnetic Field of the Earth.** *Academic Press, San Diego, 1998.*

Novotný, O.: **Motions, Gravity Field and Figure of the Earth.** *UFBA, Salvador, Bahia, 1998.*
Shearer, P. M.: **Introduction to Seismology.** *Cambridge University Press, Cambridge, 1999.*
Schubert, G. (ed.): **Treatise on Geophysics.** *Elsevier, Amsterdam, 2007.*
Schubert, G., Turcotte, D. L., Olson, P.: **Mantle Convection in the Earth and Planets.** *Cambridge University Press, Cambridge, 2001.*

Study programme P4F8A Atmospheric Physics, Meteorology and Climatology

Annotation

In the Czech Republic, this program is the only one to provide education in atmospheric physics, meteorology and climatology. It is possible to focus on a number of atmospheric research topics, including issues such as prognostic models, climate system, climate change and climate modeling, modeling of atmospheric chemistry and air quality, modeling of turbulent flow at small scales or research of higher layers of the atmosphere. The studied topics reflect the development of basic research as well as applications in the commercial and public spheres. Details of the program and workplace can be found at `http://kfa.mff.cuni.cz/` .

Board of the doctoral programme

Members of the board: `http://mff.cuni.cz/phd/or/p4f8` .

Cooperating institutes

- Institute of Atmospheric Physics, CAS
  Boční II/1401, 141 31 Praha 4
  `http://www.ufa.cas.cz/`

- Institute of Thermomechanics, CAS
  Dolejškova 1402/5, 182 00 Praha 8
  `http://www.it.cas.cz/`

Available topics of the dissertation

Topics are listed in SIS at `http://mff.cuni.cz/phd/temata/p4f8` .

Available courses

Code	Subject	Winter	Summer
NMET501	**Radiation-active Gases in Atmosphere**	2/0 Ex	—
NMET503	**Selected Topics on Dynamic Meteorology**	2/0 Ex	—
NMET507	**Predictability of Atmospheric Processes**	—	2/0 Ex
NMET508	**Numerical Forecasting Methods**	—	2/0 Ex
NMET509	**Dynamics of Ocean-Atmosphere System**	2/0 Ex	—

NMET510	**Stratosphere and Mesosphere**	2/0 Ex	—
NMET512	**Applications of Multivariate Statistical Methods in Meteorology and Climatology**	—	2/0 Ex
NMET517	**Selected Topics on Geophysical Hydrodynamics**	—	2/0 Ex
NMET518	**Climate Change Scenarios**	—	2/0 Ex
NMET519	**Climate Change Modelling**	—	2/0 Ex
NMET520	**Contemporary Issues in Synoptic Climatology**	2/0 Ex	—
NMET524	**Urban Climate**	—	3/0 Ex
NMET525	**Advanced climatology topics**	2/2 C+Ex	—
NMET526	**Numerical simulation of fluid flow**	—	2/2 C+Ex
NMET527	**Physics and chemistry of aerosols**	2/0 Ex	—
NMET528	**Air pollution modelling**	—	2/1 C+Ex
NMET529	**Aerosol Engineering II**	—	2/0 Ex
NMET530	**Mountain meteorology**	2/0 Ex	—
NMET531	**Special features of weather forecasting in Central Europe**	—	2/0 Ex
NMET532	**Numerical weather and climate models**	2/0 Ex	—
NMET533	**Satellite data in atmospheric research**	2/1 C+Ex	—
NMET534	**Middle Atmosphere Dynamics**	—	2/0 Ex
NMET535	**Advanced Cloud and Precipitation Physics**	—	2/0 Ex

Requirements for the course of doctoral study

It is strongly recommended not to extend the duration of the study beyond four years. The extension of studies makes sense in clearly justified cases. Any extension of the study beyond the four years period will be assessed individually and continuation will be recommended only in justified cases. The individual study plan (ISP) schedule should state the finalization of the dissertation for the fourth year of study. Students should have at least three peer-reviewed publications (published or accepted for publication) when defending their dissertations. Among those papers, the student should be the main author of at least two, and two papers should be published in a journal with IF. The expected schedule of publishing activity should be part of the ISP proposal. It is recommended to strive to obtain student projects from the Charles University Grant Agency. Submission of a student project proposal should be part of the ISP proposal. During the study, it is also recommended to complete an internship at a foreign institution lasting at least three months. The doctoral students should enroll in a project seminar (NMET061, NMET062) every year for the entire period of study. At least once a year, each doctoral student should present the progress of his/her dissertation at the seminar. It is recommended to pass the English exam during the first year of study. Passing the state doctoral examination is recommended during the second or third year of study after completing all ISP courses.

Requirements for the doctoral exam

The exam typically takes place in the 4th or 5th semester of the study and includes three questions.

I. Basic concepts of physics

Knowledge of general laws and concepts of physics is assumed. Knowledge of mechanics, molecular physics and thermals, thermodynamics, hydrodynamics, continuum mechanics and optics will be tested primarily in questions from subjects profiling the field.

II. Advanced parts of the field

II.1. Mandatory part

II.1.1 Dynamic meteorology

Thermodynamics of open and closed systems, phase transitions. Types of atmospheric flow, interpretation of ageostrophic components, current function and divergence potential. Theory of pressure changes, interpretation of basic equations of atmospheric dynamics, potential vorticity theorem, circulation theorems, gravitational and inertial oscillations, waves in zonal flow, baroclinic instability, energy transformation in the atmosphere, predictability of atmospheric processes, circulation at different atmospheric scales.

II.1.2 Synoptic meteorology

Use of numerical forecasting methods in weather forecasting, peculiarities of synoptic processes over Central Europe, predictions of dangerous phenomena and states, regional influences on atmospheric fronts and weather inside air masses, quasi-gostrophic approach in synoptic analysis, use of PV thinking for synoptic analysis, principles of isentropic analysis.

II.1.3 Boundary layer of the atmosphere

Turbulence in the atmosphere, transformation of kinetic energy in the boundary layer, solution of the closure problem, turbulence models, Monin's and Obuchov's similarity theory, stability parameters, interactions between the Earth's surface and the atmosphere, flow over mountain obstacles, transport and reactions of pollutants in the atmosphere.

II.1.4 Climatology

Climate system, feedback, climate predictability. Physical and chemical processes in the climate system, horizontal and vertical structure of the atmospheric and ocean circulation, interactions between the atmosphere and the ocean. Variability in the climate system, circulation indices, modes of variability. Structure of climate models, global circulation models, models for limited areas. Influences of anthropogenic activity on the climate system. The impact of urbanization on the climate.

II.2. Optional part

The doctoral student chooses one of the following thematic areas:

II.2.1 Numerical prediction methods

Types of partial differential equations used in the formulation of meteorological models (hyperbolic, parabolic and elliptic equations, including boundary value problems). Shallow water equations, baroque models. Mathematical formulation of meteorological forecasts, whole-ball models and models for limited areas. Parameterization and assimilation of data. Numerical solution of atmospheric dynamics equations.

II.2.2 Physics of clouds and precipitation

Physical properties of cloud and precipitation particles, microphysical processes in clouds, dynamics of layered and convection clouds, mesosynoptic convection systems, chemistry of clouds and precipitation, cloud electricity, use of meteorological radars in measuring precipitation, interaction of aerosols with clouds and influence on precipitation intensity - indirect radiation effects aerosols, parameterization and models of cloud formation and precipitation.

II.2.3 Atmospheric optics and acoustics

Scattering and absorption of electromagnetic radiation in the atmosphere, interpretation of basic optical and acoustic phenomena in the atmosphere, meteorological application of radars, sodars and remote sensing methods.

II.2.4 Transport of pollutants in the atmosphere

Pollutants and their sources, dispersion of pollution, deposition on the earth's surface, precipitation, basics of atmospheric chemistry, ozone chemistry, air pollution monitoring, emission measurement methods, models of pollutant propagation at various spatial scales, ecological consequences of air pollution, microphysics and aerosol chemistry.

II.2.5 Upper atmosphere

Medium atmosphere, its structure and changes during the year. Circulation in the middle atmosphere, Brewer-Dobson circulation, polar circulation. Exchange between the troposphere and stratosphere. The role of wave processes in the dynamics of the middle atmosphere. Ozone in the stratosphere, ozone destruction and the ozone hole. Influence of volcanic eruptions and solar activity.

II. 2. 6 Applied climatology

Urban climate and specifics of its modeling. Climatological aspects of solar and wind energy. Biometeorology - the issue of thermal comfort, the impact of heat waves and cold on humans and their health. Basics of phenology. Selected parts of technical climatology (indoor climate, influence of climate and weather on transport and industry).

The required content of exam can be modified in relation to the student's dissertation topic.

Recommended literature

Andrews, D. G., Holton, J. R., Leovy, C. B.: **Middle Atmosphere Dynamics.** *Academic Press, New York, 1987.*

Arya, Paul S. **Introduction to micrometeorology.** *Vol. 79. Elsevier, 2001.*

Bigg, G. R.: **The Oceans and Climate.** *Cambridge University Press, Cambridge, 1999.*

G. Brasseur, S. Solomon: **Aeronomy of the middle atmosphere (third edition).** *Atmos. Oceanograph. Sci. Lib, Springer, Dordrecht, The Netherlands (2005), (369 ff.)*

Boucher: **Atmospheric Aerosols: Properties and Climate Impacts.** *Springer, 2015.*

Cotton, W. R., Anthes, R. A.: **Storm and Cloud–Dynamics.** *Int. Geoph. Series, vol. 44, Academic Press, New York, 1989.*

Curry, J. A., Webster, P. J.: **Thermodynamics of Atmospheres and Oceans.** *Academic Press, New York, 1999.*

Dutton, J. A.: **Dynamics of Atmospheric Motion.** *Dover, New York, 1995.*

Houze Jr., R. A.: **Cloud Dynamics.** *International Geophysics Series, vol. 53, Academic Press, New York, 1993.*

Jacobson, M. Z.: **Fundamentals of Atmospheric Modeling.** *Cambridge University Press, Cambridge, 1999.*

McGuffie, K., Henderson–Sellers, A.: **A Climate Modelling Primer.** *John Wiley & Sons, New York, 1999.*

T. R. Oke, G. Mills, A. Christen, J. A. Voogt: **Urban Climates.** *Cambridge University Press, 2017.*

Pedlosky, J.: **Geophysical Fluid Dynamics.** *Springer–Verlag, Berlin, 1995.*

Peixoto, J. P., Oort, A. H.: **Physics of Climate.** *American Inst. of Physics, New York, 1992.*

Pruppacher, H. R., Klett, J. D.: **Microphysics of Clouds and Precipitation.** *Atmospheric and oceanographic sciences library, vol. 18, Kluwer Academic Publishers, Dordrecht, 1997.*

Rayner, J. N.: **Dynamic Climatology.** *Blackwell Publishers, Inc., Malden, Mass. USA, 2001.*

Seinfeld J.H., Pandis S. N.: **Atmospheric Chemistry and Physics. From Air Pollution to Climate Change.** *John Wiley and Sons, Inc., New York, Chichester, Weinheim, Brisbane, Toronto 1998*

Stull, Roland B.: **An introduction to boundary layer meteorology.** *Vol. 13. Springer Science Business Media, 2012.*

Vitaly I. Khvorostyanov,? Judith A. Curry: **Thermodynamics, Kinetics, and Microphysics of Clouds.** *1st Edition, Cambrigde University Press, 2014*

The list of recommended literature can be modified in respect to the study plan and the dissertation topic.

Study programme P4F9A Particle and Nuclear Physics

Board of the doctoral programme

Members of the board: `http://mff.cuni.cz/phd/or/p4f9` .

Cooperating institutes

- Institute of Physics, CAS
  Na Slovance 2, 182 21 Praha 8
  `http://www.fzu.cz/`

- Nuclear Physics Institute, CAS
  Husinec – Řež č. p. 130, PSČ 250 68
  `http://www.ujf.cas.cz/`

Available topics of the dissertation

Topics are listed in SIS at `http://mff.cuni.cz/phd/temata/p4f9` .

Courses

The student has to pass the compulsory lectures of the Master's programme at the faculty corresponding to his/her specialization, if they have not been passed during his/her Master study. Beside this, he/she chooses elective courses, preferably from the following list of anvanced lecture courses:

Code	Subject	Winter	Summer
NJSF008	**Biological Effects of Ionizing Radiation**	—	2/0 Ex
NJSF024	**Radioanalytical Methods**	2/0 Ex	—
NJSF030	**Quantum Field Theory at Finite Temperature**	—	2/0 Ex
NJSF031	**Classical and Quantum Chaos**	—	2/0 Ex
NJSF056	**Many Body Problem in Nuclear Structure**	2/0 Ex	—
NJSF058	**Nuclear Reactions with Heavy Ions**	2/0 Ex	—
NJSF146	**Quantum Field Theory II**	—	4/2 C+Ex
NJSF069	**Quantum Field Theory II**	—	4/2 C+Ex
NJSF070	**Particle Detectors and Accelerators**	2/0 Ex	—
NJSF071	**Introduction to supersymmetry**	2/1 Ex	—
NJSF072	**Electroweak Interactions II**	2/1 Ex	—
NJSF073	**Experimental Checks on Standard Model**	—	2/1 C+Ex
NJSF075	**Detectors for High Energy Physics**	2/0 Ex	—
NJSF079	**Quantum Field Theory III**	4/2 C+Ex	—
NJSF082	**Selected Topics on Quantum Field Theory I**	3/0 Ex	—
NJSF083	**Selected Topics on Quantum Field Theory II**	—	3/0 Ex
NJSF084	**Chiral Symmetry or Strong Interactions**	—	2/0 Ex
NJSF091	**Seminar on Particle and Nuclear Physics I**	0/2 C	—
NJSF092	**Seminar on Particle and Nuclear Physics II**	—	0/2 C
NJSF101	**Semiconductor Detectors in Nuclear and Subnuclear Physics**	2/0 Ex	—
NJSF102	**Nuclear Astrophysics**	2/0 Ex	—
NJSF107	**Statistical Nuclear Physics**	2/0 Ex	—
NJSF112	**Nuclear Processes in the Space**	2/0 Ex	—
NJSF125	**Seminar on Theoretical Particle Physics I**	0/2 C	—
NJSF126	**Seminar on Theoretical Particle Physics II**	—	0/2 C
NJSF129	**Advanced Concepts of Symmetry**	—	2/2 Ex
NJSF130	**Cosmic Rays**	—	2/0 Ex
NJSF132	**Theory of nanosccopic systems I**	2/0 Ex	—
NJSF133	**Theory of nanoscopic systems II**	—	2/0 Ex
NJSF139	**Beyond Standard Model Physics I**	2/1 Ex	—
NJSF140	**Beyond Standard Model Physics II**	—	2/1 Ex
NJSF141	**Experimental data evaluation**	—	2/0 Ex
NJSF142	**Theory of groups and algebras in particle physics**	—	2/1 Ex

NJSF143	**Statistical methods in high energy physics**	3/0 Ex	—
NJSF157	**Physics of few-body nuclear systems**	2/0 Ex	—
NJSF158	**Introduction to computational nuclear physics**	1/1 Ex	—
NJSF193	**Collective Dynamics of Manybody systems**	2/0 Ex	—
NJSF195	**Strong Interaction at High Energies**	2/0 Ex	—
NJSF196	**Microcopic Theory of Nuclei II**	2/0 Ex	—

Requirements for the course of doctoral studies

1) Study duties

In the first two years, students should attend and pass at least two specialized lectures with an exam; on an ongoing basis, attend a regular seminar of IPNP.

2) Requirements for creative activity

Research work on the topics of dissertation work; presentation at WDS (Week of Doctoral Studies) in the 1st or 2nd year of study; at least one journal publication related to the dissertation topic; presentation of results at a seminar or appropriate conference.

3) Internship requirements

In agreement with the standards of the study programmes at Charles University, part of the study obligations should be done at a foreign institution for a total duration of at least one month, or another form of direct participation in international cooperation. A longer internship abroad is desirable but not a requirement.

4) Other obligations

Participation at an appropriate winter or summer school or conference; English language exam; supervision of undergraduate tutorial classes, or in a practical course in nuclear physics.

Requirements for the state doctoral exam

The selection of questions takes into account the student's specialization and the topic of the doctoral thesis.

I. Broader basis

Formal scheme and basic postulates of quantum theory. Uncertainty relations. The Schrödinger equation and its solution for simple systems in the framework of non-relativistic quantum mechanics. Quantization and addition of angular momenta. Spin. Approximate methods of quantum mechanics. Fundamentals of quantum scattering theory. Theory of many-particle systems, second quantization, systems of identical particles, self-consistent field method. Symmetry and conservation laws. Fundamentals of special relativity. Equations of relativistic mechanics and classical field theory. Poincaré group. Klein-Gordon and Dirac equations, their solutions for free particles and particles in electromagnetic field. Fundamentals of quantum field theory. Feynman diagrams. Quantum electrodynamics processes in the lowest order. Diagrams with one closed loop. Basic techniques of regularization and renormalization.

II. Particle Physics

Detection methods for registration of elementary particles. Particle accelerators and detectors. Systematics and measurement of elementary particle characteristics.

Genesis of the current Standard Model of elementary particles. Hadron physics: quark model, parton model, evidence for color. Fundamentals of quantum chromodynamics: interaction Lagrangian, running coupling constant, evolution equations. Experimental tests of quantum chromodynamics. Theoretical foundations and experimental tests of the standard model of electroweak interactions. Neutral and charged currents. Properties of intermediate bosons. Higgs boson. Elementary processes in the lowest order. Violation of CP-symmetry. Kobayashi-Maskawa matrix. Neutrino oscillations.

III. Nuclear Physics

Basic characteristics of nuclei. Nuclear forces, deuteron, few-nucleon systems. Degrees of freedom of nuclear dynamics, single particle and collective motions. Electromagnetic transitions. Beta transitions. Alpha transitions. Mean field and short and long range residual interactions. Pair correlations, Hartree-Fock-Bogoliubov method. Microscopic models to describe collective excitations. Basic concepts and mechanisms of nuclear reactions. Nuclear fission and the principle of nuclear reactors. Nuclear astrophysics. Passage of charged particles, neutrons and photons through matter. Nuclear radiation detectors and spectrometers. Measurement of temporal and angular correlations. Charged particle accelerators and neutron sources.

Recommended literature

Cahn, R., Goldhaber, G.: **Experimental foundations of particle physics.** *Cambridge University Press, Cambridge, 1989.*

Cejnar, P.: **A Condensed Course of Quantum Mechanics.** *Karolinum, Praha, 2013.*

Cheng, T.–P., Li, L.–F.: **Gauge theory of elementary particle physics.** *Clarendon Press, Oxford, 1984.*

Ferbel, T.: **Experimental techniques in high energy nuclear and particle physics.** *World Scientific, Singapore, 1991.*

Greiner, W., Maruhn, J. A.: **Nuclear Models.** *Springer–Verlag, New York, 1996.*

Griffiths, D.: **Introduction to Elementary Particles.** *Wiley, New York, 1987.*

Heyde, K.: **Basic Ideas and Concepts in Nuclear Physics.** *Institute of Physics Publishing, London, 1994.*

Heyde, K.: **The Nuclear Shell Model.** *Springer–Verlag, New York, 1994.*

Hořejší, J.: **Fundamentals of electroweak theory.** *Karolinum, Praha, 2002.*

Itzykson, C., Zuber, J.–B.: **Quantum field theory.** *McGraw–Hill, New York, 1980.*

Knoll, G. F.: **Radiation Detection and Measurement.** *Wiley, New York, 2000.*

Leo, W. R.: **Techniques for nuclear and particle physics experiments.** *Springer, Berlin, 1994.*

Mandl, F., Shaw, G.: **Quantum Field Theory.** *Wiley, New York, 1988.*

Nilsson, S. G., Ragnarsson, I.: **Shapes and Shells in Nuclear Structure.** *Cambridge University Press, Cambridge, 1995.*

Peskin, M., Schroeder, D.: **An Introduction to quantum field theory.** *Addison–Wesley, Reading, 1995.*

Ring, I. P., Schuck, P.: **The Nuclear Many–Body Problem.** *Springer–Verlag, New York, 1980.*

Sakurai, J.J., Napolitano, J.J.: **Modern Quantum Mechanics.** *Addison-Wesley, 2011.*
Thomson, M.: **Modern Particle Physics.** *Cambridge University Press, 2013.*
Weinberg, S.: **The quantum theory of fields I, II.** *Cambridge University Press, Cambridge, 1995, 1996.*
Wilson, E.: **An Introduction to Particle Accelerators.** *Oxford University Press, Oxford 2001.*

Study programme P4F11A Mathematical and Computer Modeling

Annotation

This study branch is a combined one between mathematics and physics. It is focused on modelling in physics of solids, liquids, gases and plasma, with applications in material sciences, chemistry, biology and medicine. According to the subject of the thesis, it is possible to devote to continuum, particle of hybrid modelling with accents either in mathematics or in physics. The continuum modelling is focused on the study of models of continuum mechanics and thermodynamics of fluids (i.e., liquids or gases) and solids or on the related mathematical and numerical analysis of the corresponding systems of partial differential equations and possibly on their numerical solution. The particle and hybrid modelling are focused on the study of macromolecules, thin layers and surfaces and on the study of low- or high-temperature plasma in close connection to experimental data, often with the aim to help with interpretation of the obtained experimental results and developments of new diagnostic methods.

Board of the doctoral programme

Members of the board: `http://mff.cuni.cz/phd/or/p4f11` .

Cooperating institutes

- Institute of Mathematics, CAS
  Žitná 25, 115 67 Praha 1
  `http://www.math.cas.cz`

- Institute of Thermomechanics, CAS
  Dolejškova 1402/5, 182 00 Praha 8
  `http://www.it.cas.cz/`

Available topics of the dissertation

Topics are listed in SIS at `http://mff.cuni.cz/phd/temata/p4f11` .

Courses

The student chooses the subjects in collaboration with the supervisor with the agreement of the Board of the study programme. It is possible to take any subject taught at the Charles University, in case of need after agreement also at other universities (Czech Technical University, University of Chemistry and Technology etc.) The offer includes, in particular, subjects of the master-degree studies of mathematical modelling and numerical mathematics that the student has not passed in the previous study. Their list is given below, in the frame of requirements for the state doctoral exam.

Code	Subject	Winter	Summer
NMMO561	**Regularity of solutions of Navier-Stokes equations**	2/0 Ex	—
NMMO533	**Nonlinear Differential Equations and Inequalities 1**	3/1 C+Ex	—
NMMO534	**Nonlinear Differential Equations and Inequalities 2**	—	3/1 C+Ex
NMMA452	**Seminar on Partial Differential Equations**	0/2 C	0/2 C
NMMA431	**Seminar on Differential Equations**	0/2 C	0/2 C
NMMA583	**Qualitative Properties of Weak Solutions to Partial Differential Equations**	2/0 Ex	—
NMMA584	**Regularity of Weak Solutions to Partial Differential Equations**	—	0/2 C
NMMA621	**Analysis of Mathematical Models of Bodies Moving through Fluids I**	2/0 Ex	—
NMMA622	**Analysis of Mathematical Models of Bodies Moving through Fluids II**	—	2/0 Ex
NMMA623	**New results in the theory of Euler equations**	—	2/0 Ex
NMNV461	**Techniques for a posteriori error estimation**	2/0 Ex	—
NMNV462	**Numerical Modelling of Electrical Engineering Problems**	—	2/0 Ex
NMNV463	**Modelling of materials — theory, model reduction and efficient numerical methods**	0/2 C	0/2 C
NMNV464	**A Posteriori Numerical Analysis Based on the Method of Equilibrated Fluxes**	—	2/0 Ex
NMNV561	**Bifurcation Analysis of Dynamical Systems 1**	2/0 Ex	—
NMNV562	**Bifurcation Analysis of Dynamical Systems 2**	—	2/0 Ex
NMNV627	**Modern Algorithms in Numerical Optimisation**	2/0 Ex	—
NGEO112	**Fourier Spectral Analysis**	—	2/1 C+Ex
NGEO076	**Inverse Problems and Modelling in Physics**	—	2/0 Ex
NGEO102	**Inverse modeling in geodynamics**	2/0 Ex	—
NEVF160	**Modern Computational Physics I**	2/1 MC	—
NEVF161	**Modern Computational Physics II**	—	2/1 MC

NEVF523	**Numerical Methods of Computational Physics I**	2/2 Ex	—
NEVF529	**Numerical Methods of Computational Physics II**	—	2/2 Ex
NEVF525	**Plasma Physics and Computer Plasma Modelling I**	2/2 C	—
NEVF531	**Plasma Physics and Computer Plasma Modelling II**	—	2/2 Ex
NBCM321	**Fundamentals of Computer Physics I**	2/2 MC	—
NBCM322	**Fundamentals of Computer Physics II**	—	2/2 Ex
NMMO566	**Plasticity and creep**	—	2/0 Ex

Requirements for the state doctoral exam

The exam consists of three parts:

I — Methods of analysis of partial differential equations
II — Methods of numerical mathematics and scientific computations
III — Methods of continuum physics and plasma physics

The supervisor in coordination with the student and the guarantor of the programme chooses from each part one subject. One subject (so called the special one) is directed towards the contents of the doctoral thesis; it typically concerns the study of newest articles or books in the given field. It is assumed that this subject is contained in one of the parts I, II or III. The subjects chosen from the remaining parts are typically such that they form extra knowledge above the knowledge of the student from the master-degree. It is usually a part covered by one or two advanced lectures which the student passed during the doctoral studies or whose content the student studied by him/herself. The nowadays offer includes, e.g., the following lectures:

I Methods of analysis of partial differential equations

Code	Subject	Winter	Summer
NMMO539	**Mathematical Methods in Mechanics of Non-Newtonian Fluids**	2/0 Ex	—
NMMO535	**Mathematical Methods in Mechanics of Solids**	2/0 Ex	—
NMMO532	**Mathematical Theory of Navier-Stokes Equations**	—	2/0 Ex
NMMO536	**Mathematical Methods in Mechanics of Compressible Fluids**	—	2/0 Ex
NMMO561	**Regularity of solutions of Navier-Stokes equations**	2/0 Ex	—
NMMO533	**Nonlinear Differential Equations and Inequalities 1**	3/1 C+Ex	—
NMMO534	**Nonlinear Differential Equations and Inequalities 2**	—	3/1 C+Ex
NMMA531	**Partial Differential Equations 3**	2/0 Ex	—

II Methods of numerical mathematics and scientific computations

Code	Subject	Winter	Summer
NMMO537	**Saddle Point Problems and Their Solution**	—	2/2 C+Ex
NMNV407	**Matrix Iterative Methods 1**	4/0 Ex	—
NMNV436	**Finite Element Method 2**	—	2/2 C+Ex
NMNV537	**Mathematical Methods in Fluid Mechanics 1**	2/0 Ex	—
NMNV538	**Mathematical Methods in Fluid Mechanics 2**	—	2/0 Ex
NMNV464	**A Posteriori Numerical Analysis Based on the Method of Equilibrated Fluxes**	—	2/0 Ex
NMNV540	**Fundamentals of Discontinuous Galerkin Method**	—	2/0 Ex
NEVF523	**Numerical Methods of Computational Physics I**	2/2 Ex	—
NEVF529	**Numerical Methods of Computational Physics II**	—	2/2 Ex

III Methods of continuum physics and plasma physics

Code	Subject	Winter	Summer
NMMO432	**Classical Problems of Continuum Mechanics**	—	2/1 C+Ex
NMMO543	**Modelling in biomechanics**	3/0 C+Ex	—
NMMO541	**Theory of Mixtures**	2/1 C+Ex	—
NOFY026	**Classical Electrodynamics**	—	2/2 C+Ex
NTMF034	**Electromagnetic Field and Special Theory of Relativity**	—	2/1 Ex
NEVF525	**Plasma Physics and Computer Plasma Modelling I**	2/2 C	—
NEVF157	**Computer modelling in plasma physics II**	—	1/1 MC
NEVF526	**Computational Physics I**	2/2 C	—
NBCM322	**Fundamentals of Computer Physics II**	—	2/2 Ex
NGEO102	**Inverse modeling in geodynamics**	2/0 Ex	—

Recommended literature

Addison, P. S.: **The Illustrated Wavelet Transform Handbook.** *Institute of Physics Publishing, Bristol, 2002.*

Callen, H. B.: **Thermodynamics and an introduction to thermostatics.** *John Wiley & Sons, New York, 1985.*

Ciarlet, P. G.: **Mathematical elasticity. Vol. I. Three-dimensional elasticity.** *Studies in Mathematics and its Applications, 20. North-Holland Publishing Co., Amsterdam, 1988.*

Ciarlet, P. G.: **Linear and nonlinear functional analysis with applications.** *SIAM, Philadelphia, 2013.*

Ciarlet, P. G., Lions, J.L. (eds.): **Finite Element Methods. Handbook of Numerical Analysis, part 1.** *3rd ed. North–Holland–Elsevier, 2007.*

Elman, H., Silvester, D., Wathen, A.: **Finite Elements and Fast Iterative Solvers (with applications in incompressible fluid dynamics).** *Oxford Science Publications, Oxford University Press, Oxford, 2008.*

Evans, L.: **Partial Differential Equations.** *AMS, 2010 (druhé rozšířené vydání).*

Feireisl, E., Novotný, A.: **Singular Limits in Thermodynamics of Viscous Fluids.** *Advances in Mathematical Fluid Mechanics, Birkhäuser Basel, 2009, 2.vydání 2017.*

Feireisl, E.: **Dynamics of viscous compressible fluids.** *Oxford Lecture Series in Mathematics and its Applications, 26. Oxford University Press, Oxford, 2004.*

Feireisl, E. Karper, T. G. Pokorný, M.: **Mathematical theory of compressible viscous fluids. Analysis and numerics.** *Advances in Mathematical Fluid Mechanics. Lecture Notes in Mathematical Fluid Mechanics. Birkhäuser/Springer, Cham, 2016.*

Feistauer, M., Felcman, J., Straškraba, I.: **Mathematical and computational methods for compressible flow.** *Numerical Mathematics and Scientific Computation. The Clarendon Press–Oxford University Press, Oxford, 2003.*

Feistauer, M.: **Mathematical Methods in Fluid Mechanics.** *Longman Scientific and Technical Series, Harlow, 1993.*

Gurtin, M. E., Fried, E., Anand, L.: **The mechanics and thermodynamics of continua.** *Cambridge University Press, Cambridge, 2010.*

Gershenfeld, N.: **The Nature of Mathematical Modelling.** *Cambridge University Press, Cambridge, 1999.*

Haille, J. M.: **Molecular Dynamics Simulation: Elementary Methods.** *J. Willey, New York, 1992.*

Hockney, R. W., Eastwood, J. W.: **Computer Simulation Using Particles.** *Taylor & Francis, New York, 1988*

Chadwick, P.: **Continuum Mechanics: Concise Theory and Problems.** *2nd ed. Dover Publications, Dover, 1999.*

Chen, F. F.: **Introduction to Plasma Physics and Controlled Fusion.** *Springer, New York, 2006.*

Kružík, M., Roubíček, T.: **Mathematical methods in continuum mechanics of solids.** Interaction of Mechanics and Mathematics. Springer, Cham, 2019.

Landau, D. P., Binder, K.: **A Guide to Monte Carlo Simulation in Statistical Physics.** *Cambridge University Press, Cambridge, 2005.*

Landau, L. D., Lifshitz, E. M.: **Statistical Physics. Vol. 5.** (3rd ed.) *Butterworth-Heinemann, 1980.*

Lebon, G., Jou, D., Casas-Vázquez, J.: **Understanding non-equilibrium thermodynamics5.** *Springer, 2008.*

Liesen, J., Strakoš, Z.: **Krylov subspace methods. Principles and analysis.** *Numerical Mathematics and Scientific Computation, Oxford University Press, Oxford, 2013.*

Málek, J., Nečas, J., Rokyta, M., Růžička, M.: **Weak and Measure–valued solutions to evolutionary equations.** *Chapmann & Hall, 1996.*

Málek, J., Rajagopal, K.R.: **Mathematical issues concerning the Navier–Stokes equations and some of its generalizations.** *Evolutionary equations, vol. II, p. 371–459, Handb. Differ. Equ., ed. C.M. Dafermos, E. Feireisl. Elsevier/North–Holland, Amsterdam, 2005.*

Málek, J., Strakoš, Z.: **Preconditioning and the conjugate gradient method in the context of solving PDEs.** *SIAM Spotlights, 1, SIAM, Philadelphia, 2015.*

Novotný, A., Straškraba, I.: **Introduction to the mathematical theory of compressible flow.** *Oxford Lecture Series in Mathematics and its Applications, 27. Oxford University Press, Oxford, 2004.*

Ogden, R. W.: **Nonlinear elastic deformations.** *Ellis Horwood Series: Mathematics and its Applications. Ellis Horwood Ltd., Chichester; Halsted Press [John Wiley Sons, Inc.], New York, 1984.*

Pavelka, M., Klika, V., Grmela, M.: **Multiscale Thermo-dynamics: Introduction to Generic.** *De Gruyter, 2018.*

Perthame, B.: **Transport equations in biology.** *Frontiers in Mathematics. Birkhäuser Verlag, Basel, 2007.*

Phan—Thien, N.: **Understanding Viscoelasticty.** *Springer, 2002.*

Pratt, W. K.: **Digital Image Processing.** *Wiley, New York, 1991.*

Press, W. H. et al.: **Numerical Recipes — The Art of Scientific Computing.** *3rd ed. Cambridge University Press, Cambridge, 2007.*

Rapaport, D. C.: **The Art of Molecular Dynamics Simulations.** *Cambridge University Press, Cambridge, 1995.*

Robinson, J.C. Rodrigo, J.L. Sadowski, W.: **The three-dimensional Navier-Stokes equations. Classical theory.** *Cambridge Studies in Advanced Mathematics, 157. Cambridge University Press, Cambridge, 2016.*

Roubíček, T.: **Nonlinear Partial Differential Equations with Applications. Second edition.** *International Series of Numerical Mathematics, 153. Birkhäuser/Springer Basel AG, Basel, 2013.*

Spencer, A. J. M.: **Continuum Mechanics.** *Dover Books on Physics, Dover Publications, Dover, 2004.*

Temam, R.: **Navier–Stokes equations and nonlinear functional analysis.** *2nd ed. CBMS–NSF Regional Conference Series in Applied Mathematics, 66. Society for Industrial and Applied Mathematics (SIAM), Philadelphia, PA, 1995.*

Truesdell, C.; Noll, W.: **The non-linear field theories of mechanics. Third edition. Edited and with a preface by Stuart S. Antman.** *Springer-Verlag, Berlin, 2004.*

Tsai, T.-P.: **Lectures on Navier-Stokes equations.** *Graduate Studies in Mathematics, 192. American Mathematical Society, Providence, RI, 2018.*

Wilmanski, K.: **Continuum Thermodynamics. Series on Advances in Mathematics for Applied Sciences, Vol. 77.** *World Scientific, 2008.*

Yosida, K.: **Functional Analysis.** *Springer, 1995.*

Zeidler, E.: **Applied Functional Analysis.** *Springer–Verlag, Berlin, 1995.*

Zeidler, E.: **Nonlinear Functional Analysis and its Applications, vol. I–V.** *Springer–Verlag, Berlin, 1986–1995.*

Study programme P4F12A Physics Education and General Problems of Physics

Board of the doctoral programme

Members of the board: `http://mff.cuni.cz/phd/or/p4f12` .

Cooperating institutes

- Astronomical Institute, CAS
  Fričova 298, 251 65 Ondřejov
  `http://www.asu.cas.cz/`

Available topics of the dissertation

Topics are listed in SIS at `http://mff.cuni.cz/phd/temata/p4f12` .

Available courses

Code	Subject	Winter	Summer
NDFY029	**Problems of Physics Education**	0/2 C	0/2 C
NDFY054	**Modern Trends in Physics Education**	—	0/2 C
NDFY064	**Ph.D. Students' Seminar f12 I**	0/1 C	—
NDFY065	**Ph.D. Students' Seminar f12 II**	—	0/1 C
NDFY066	**Physical Worldview II**	—	0/2 C
NDFY071	**Introduction to Bibliographic and Scientific Research I**	0/1 C	—
NDFY072	**Introduction to Bibliographic and Scientific Research II**	—	0/1 C
NDFY042	**Development of Physical Experiments**	0/2 C	—
NDFY070	**Development of Physical Experiments II**	—	0/2 C
NPED015	**Seminar on Pedagogy I**	0/2 C	—
NPED016	**Seminar on Pedagogy II**	—	0/2 C
NPOZ008	**Physics as an Adventure of Discovery**	—	0/3 C

Requirements for the doctoral exam

The exam consists of three parts: I. Broader basis, II. Parts of physics related to the topic of the dissertation, III. Specialization.

I. Broader basis

1. Space and time, inertial and non-inertial systems, relativistic kinematics and dynamics.
2. Energy, momentum and angular momentum in various fields of physics.
3. Dynamical description of various systems (equations of motion, variational formulation of physics laws, field equations).
4. Oscillator in both classical and quantum physics.
5. Basics of classical electrodynamics (building theory from experiments as well as deductive derivation from the Maxwell's equations).
6. Potentials and their significance in physics.

7. Waves (mechanical and electromagnetic, properties, propagation, excitation).
8. Interaction of electromagnetic radiation with matter (classical and quantum level).
9. Microworld-specific laws (quantum description, basic concepts of nuclear and particle physics, applications).
10. Basic principles and applications of thermodynamics and statistical description.
11. Macroscopic properties of matter and their microscopic interpretation.
12. Measurements of physical quantities (quantities and their units, measurement methods, fundamental physical constants and their measurement).
13. Physical nature of phenomena from everyday life and technical practice (the ability of theories to explain the observed phenomena, applications of physics results).
14. Limits of validity of physical theories (relation of classical, quantum and relativistic physics, other examples such as electrostatics-electrodynamics).

A general overview of physics as in the Feynman course is assumed. This includes an explanation of basic physical laws and their consequences with experimental results and applications. Emphasis is also placed on the ability to explain the topic in more elementary ways.

II. II. Parts of physics related to the topic of the dissertation

Due to the breadth of the topics of theses falling within the given field, the commission can determine the requirements for every student individually. In this part of the exam, the candidate must demonstrate a deeper physical insight into the chosen part of physics related to the topic of his/her dissertation.

III. Specialization

In the specialization the applicant chooses one of the following: a) didactics of physics, b) philosophy and methodology of physics, c) history of physics. The student must demonstrate a general overview of the area, be able to explain its starting points, basic concepts and their connections (including links to individual fields of physics), methodology of relevant research and the most important results. Following the more specific focus of the dissertation, the commissions can adjust the requirements in the field of specialization for each student individually.

The adept must demonstrate a general overview of the field, be able to explain its background, basic concepts and their context (including links to individual fields of physics), methods of work as well as the most important results. In the case of didactics of physics also their applications in education, e.g., settings goals of teaching, choosing teaching methods, problem-solving methods, didactic functions of the experiment, and evaluation of the teaching results.

The extent is given by the literature bellow. Following the most specific focus of the dissertation, the commission can adjust the requirements in the field of specialization for every student individually.

Recommended literature

Following the focus of the dissertation, the list of recommended literature can be adjusted for each student individually.

Bell, J.: **Doing your research project: a guide for first-time researchers in education, health and social science.** *Open University Press, UK 2005.*

Bennet, J.: **Teaching and learning science: a guide to recent research and its applications.** *Continuum, New Ed edition, London, UK 2004.*

Buchwald, J.Z., Fox, R. (eds.): **The Oxford Handbook of the history of physics.** *Oxford University Press - print publication 2013, online publication 2017 (DOI: 10.1093/oxfordhb/9780199696253.013.2).*
Clark-Carter, D.: **Quantitative psychological research.** *Psychology Press, NY 2010 (3rd edition).*
Goldstein, H., Poole, Ch., Safko, J.: **Classical Mechanics.** *Addison Wesley, 2002 (3rd edition).*
Denzin, N.K., Lincoln, Y.S. (eds.): **The SAGE handbook of qualitative research.** *SAGE Publications, LA 2005.*
Feynman, R.P., Leighton, R.B., Sands, M.: **The Feynman lectures on physics (Vol. 1-3).** *Available online at* `https://www.feynmanlectures.caltech.edu/` .
Fraser, J.B., McRobie, C.J., Sands, M.: **Second international handbook of science education.** *Springer, Dordrecht 2012.*
Gilbert, J.: **Science education: major themes in education (Vol. 1-4).** *Routledge and CRC Press, 2006.*
Goodwin, J.C.: **Research in psychology. Methods and designs.** *Wiley, NJ 2010 (6th edition).*
Hattie, J.: **Visible Learning: A Synthesis of Over 800 Meta-Analyses Relating to Achievement.** *Routledge, London, UK 2009.*
Heywood, D., Parker, J.: **The Pedagogy of Physical Science.** *Springer 2010.*
Littleton, K., Wood, C., Staarman, K.J.: **International Handbook of Psychology in Education.** *Emerald Group Publishing Limited, Bingley, UK 2010.*
Hollander, M., Wolfe, D.A.: **Nonparametric Statistical Methods.** *John Willey Sons, NY 1999 (2nd edition).*
Korthagen, F.A.J., Kessels, J., Koster, B. Lagerwerf, B., Wubbels, T.: **Linking practice and theory: The pedagogy of realistic teacher education.** *Lawrence Erlbaum Associates, Mahwah, N.J. 2001.*
Kuhn, T.S.: **The structure of scientific revolutions.** *University of Chicago Press, 1996 (3rd edition).*
Mawwell, J.A.: **Quantitative research design: an interactive approach.** *SAGE Publications, LA 2013.*
Popper, K.: **The logic of scientific discovery.** *Taylor Francis Ltd, UK 2002 (2nd edition).*
Teddlie, C., Tahakkori, A.: **Foundations of mixed methods research.** *SAGE Publications, LA 2009.*
Yin, R.K.: **Case study research: design and methods.** *SAGE Publications, LA 2003.*
Jackson, D.: **Classical Electrodynamics.** *John Willey Sons Inc., Hoboken, NJ 1998 (3rd edition).*
Shadish, W.R., Cook, T.D., Campbell, D.T.: **Experimental and Quasi-Experimental Designs for Generalized Causal Inference.** *Belmond, CA, Wadsworth 2002.*

Study programme P4F13A Physics of Nanostructures and Nanomaterials

Board of the doctoral programme

Members of the board: `http://mff.cuni.cz/phd/or/p4f13` .

Cooperating institutes

- Institute of Physics, CAS
  Na Slovance 2, 182 21 Praha 8
  `http://www.fzu.cz/`

- Institute of Photonics and Electronics, CAS
  Chaberská 57, 182 51 Praha 8
  `http://www.ufe.cz/`

- J. Heyrovsky Institute of Physical Chemistry, CAS
  Dolejškova 2155/3, 182 23 Praha 8
  `http://www.jh-inst.cas.cz/`

Available topics of the dissertation

Topics are listed in SIS at `http://mff.cuni.cz/phd/temata/p4f13` .

Courses

Compulsory courses

Code	Subject	Winter	Summer
NEVF534	**Physics of Low-dimensional Structures**	2/0 Ex	2/0 Ex
NFPL199	**Physical Methods in Nanostructure Studies**	—	2/0 Ex
NEVF535	**Nanomaterials I**	2/0 Ex	2/0 Ex
NEVF533	**Physical Methods of Nanostructure Technology**	2/0 Ex	2/0 Ex
NFPL187	**Seminar on Nanomaterials: Physics, Technology, Applications I**	0/2 C	—
NFPL188	**Seminar on Nanomaterials: Physics, Technology, Applications II**	—	0/2 C

Other lecture courses and seminars from related fields, elective in respect to the dissertation topic, e.g.:

Code	Subject	Winter	Summer
NOOE070	**Optics of Nanomaterials and Nanostructures**	—	2/0 Ex
NOOE121	**Methods of Laser Spectroscopy in Semiconductor Spintronics**	2/0 Ex	2/0 Ex

NBCM101	**Detection and Spectroscopy of Single Molecules**	2/0 Ex	—
NEVF515	**Methods of Physics of Surfaces and Thin Films I**	—	2/0 Ex
NEVF516	**Methods of Physics of Surfaces and Thin Films II**	2/0 Ex	—
MC240P58	**Nanomaterials II**	—	2/0 Ex
MC240P92	**Methods for the study of solid-state materials and surfaces**	2/0 Ex	—
NOOE003	**Materials and Technology in Optoelectronics**	2/0 Ex	—
NOOE009	**Optoelectronics and Optical Properties of Solids**	—	2/0 Ex
NFPL013	**X-ray Scattering on Thin Films**	2/0 Ex	—
NFPL173	**Electron Transport in Quantum Systems**	—	3/0 Ex
NFPL085	**Electronic Theory of Solids**	—	2/0 Ex

Requirements for the state doctoral exam

During the examination, the student will receive three questions from the areas defined below: I. Broad base, II. Important physical and technological aspects of nanostructures, and III. A question related to the topic of the theses (a list of up to five questions will be provided by the supervisor, e.g., via email to the student at the study school's chair at least two weeks before the date of the examination).

I. Broad base

I.1. I.1. Structural properties and dynamics of the nanoscale systems

General symmetry in solids; crystallography of 3D, 2D, and 1D nanomaterials. Relaxation and reconstruction of surfaces.

Vibrational properties of the lattice - phonons in nanostructures and surface phonon states.

Mechanical properties of nanostructures; plastic, and elastic deformation.

I.2. Electronic structure, optical and magnetic properties

Electrons in the periodic medium, band structure, chemical bonding. Consequences of the reduced dimensions to electronic states of solids (size effect, quantum confinement).

Surface electronic states, electronic states in low-dimensional systems. Linear response theory, optical transitions.

Transport properties - transport equations, scattering mechanisms, quantum Hall effect.

Magnetic properties of low-dimensional structures.

II. Important physical and technological aspects of nanostructures

II.1. Preparation methods

Physical and chemical methods of growth of thin films, nanoparticles, and other important classes of nanomaterials.

The classical theory of nucleation, theory of thin-film growth, processes of self-assembly.

Methods of preparation of nanostructures used in the dissertation.

II.2. Characterization methods

Diffraction methods (X-ray and electron diffraction, neutron scattering).

Electron microscopy, ion microscopy, AFM, STM, and other scanning methods.

Methods of surface electron and ion spectroscopy (UPS, XPS, AR PES, AES, etc.).

Optical methods of studying nanostructures (UV / VIS, FTIR spectroscopy, ellipsometry, Raman scattering, nonlinear optical spectroscopy).

Transport methods (electrical conductivity, magnetoresistance, and Hall effect).

Electrochemical methods and other special experimental techniques according to the focus of the doctoral thesis.

III. Selected parts of the problem solved within the topic of the dissertation thesis.

Reccomended literature

Aoki, H., Dresselhaus, M.S.(eds): **Physics of graphene.** *Springer, 2014.*

Bhushan, B. (ed.): **Springer Handbook of Nanotechnology.** *2nd ed. Springer, 2007.*

Bimberg, D. et al.: **Quantum Dot Heterostructures.** *J. Wiley, 1999.*

Delerue, C., Lannoo, M.: **Nanostructures, theory and modeling.** *Springer, 2004.*

Edelstein, A. S., Cammarata, R.: **Nanomaterials, Synthesis, Properties and Application.** *Inst. of Physics Publishing, 1996.*

Gabrys, B. J. (ed.): **Applications of Neutron Scattering to Soft Condensed Matter.** *Gordon and Breach Science Publisher, 2000.*

Grundmann, M.: **Nano–optoelectronics.** *Springer, 2002.*

Guozhong, C.: **Nanostructures and Nanomaterials.** *Imp. Coll. Press, 2004.*

Herman, M. A., Richter, W., Sitter, H.: **Epitaxy: Physical Principles and Technical Implementation.** *Springer, 2004.*

Hirsch, P.: **Electron Microscopy of Thin Crystals.** *R. E. Krieger Publishing, 1977.*

Lowe, T. C., Valiev, R. Z. (eds.) **Investigations and Applications of Severe Plastic Deformation.** *NATO Science Series 80, Kluwer Academic Publishers, Dordrecht, 2000.*

Lu, G. Q., Zhao, X. S.: **Nanoporous Materials Science and Engineering.** *Imperial College Press, 2004.*

Michely, T., Krug, J.: **Atoms, Mounds and Atoms, Patterns and Processes in Crystal Growth Far from Equilibrium.** *Springer, 2004.*

Mills, D. J., Bland, J. A. C. (eds): **Nanomagnetism.** *Elsevier, 2006.*

Ozin, G. A., Arsenault, A. C.: **Nanochemistry.** *RSC Publ., 2005.*

Pietsch, U. et al.: **High–resolution x–ray scattering from thin films and nanostructures.** *Springer, 2004.*

Reich, S., Thomsen, C., Maultzsch, J.: **Carbon Nanotubes.** *J. Wiley, 2003.*

Roe, R.–J.: **Methods of x–ray and Neutron Scattering in Polymer Science.** *Oxford University Press, Oxford, 2000.*

Shchukin, V. A., Ledentsov, N. N., Bimberg, D.: **Epitaxy of Nanostructures.** *Springer, 2004.*

Venables, J. A.: **Introduction to Surface and Thin Film Processes.** *Cambridge University Press, Cambridge, 2000.*
Vollath, D., **Nanomaterials.** *Wiley, 2010.*
Williams, D. B., Carter, C. B.: **Transmission Electron Microscopy, a Textbook for Material Science.** *Plenum Press, New York, 1996.*
Wolf, E. L.: **Nanophysics and Nanotechnology, An Introduction to Modern Concepts in Nanoscience.** *Wiley–VCH, Berlin, 2006.*
Xu, Y., David, D., Nitta, J. (eds): **Handbook of Spintronics** *Springer, 2015.*

A lecturer and supervisor may expand the list of suggested literature by publications and review articles related to the topic of the dissertation.