Graduate School in Science – Theoretical Physics
(Astrophysics, Field Theory, Mathematical Physics, Modeling and Simulation)

Specialization of theoretical physics offers a sound preparation in fundamental theoretical subjects like quantum mechanics and field theory, with a range of other possibilities. With a focus on mathematical methods of theoretical physics, their practical applications and their interdisciplinary character it opens a wide set of possibilities for further career in science and industry.

Prerequisites of admission:

- Bachelor's degree with a major in physics
- Bachelor's degree with courses in the following subjects or their equivalents: general physics, electricity and magnetism, classical mechanics, optics, thermodynamics, calculus, linear algebra, elements of differential equations

1st year courses

title	kind of activity	hours/ week	hours/ year	form of crediting	credits
General School Seminar	Seminar (*)	2	60	Participation	4
Elements of Quantum Mechanics (1)	Lectures (*) Tutorials (*)	2 2	30 30	Exam Test	8
Quantum Mechanics II	Lectures (*) Tutorials (*)	2 2	30 30	Exam Test	8
Mathematical Methods and Differential Equations	Lectures Tutorials	2 2	30 30	Exam	8
Introduction to Electrodynamics	Lectures (*) Tutorials (*)	2 2	30 30	Exam Test	8
Introduction to Field Theory	Lectures	2	30	Exam/test	4
Simulations in Physics (Monte Carlo Methods)	Lectures, Tutorials	2 2	30 30	Exam/essay/test	7
Doing Science with Mathematica and Maple (1)	Lecture/Tutorials	2	30	Project	3
Introduction to Theoretical Methods in Biophysics	Lectures	2	30	Arranged with Lecturer	3
Statistical Physics (1)	Lectures Tutorials	2 2	30 30	Exam Test	4
Introduction to Special and General Relativity	Lectures Tutorials	2 2	30 30	Exam Test	6
Introduction to Observational Astronomy	Lectures	2	30	Exam	4
Tutorial	Tutorials	2	60	Arranged with tutor	4

Required number of credits to complete 1st year: **44** (courses)
+ **10** (individual project assigned by tutor)

(*) obligatory courses
(1) course joined with other specialization

2nd year courses

title	kind of activity	hours/ week	hours/ year	form of crediting	credits
General School Seminar	Seminar	2	60	Participation	4
Introduction to Nonlinear Physics	Lectures	2	30	Arranged with lecturer	4
Phase Transitions and Critical Phenomena (1)	Lectures	2 2	30 30	Arranged with lecturer	6
Introduction to Particle Physics	Lectures	2	30	Arranged with lecturer	3
Modern Theoretical Physics Seminar	Seminar	2	30	Project/essay	2
Doing Science with Mathematica and Maple (1)	Lectures/tutorial	2	30	Project	3
Advanced Quantum Field Theory	Lectures Tutorials	2 2	30 30	Exam/essay Test/	8
Introduction to Econophysics	Lectures	2	45	Arranged with lecturer	4
Geometry in Theoretical Physics	Lectures	2	30	Arranged with lecturer	4
Computer Simulations and Modeling (2)	Lectures Tutorials	2 2	30 30	Arranged with lecturer	7
Astrophysics: Physics of Stars	Lectures	2	30	Arranged with lecturer	4
Cosmology: guide to the Universe	Lectures	2	30	Arranged with lecturer	4
Time Series Analysis	Lectures	2	30	arranged with lecturer	4
Practical Quantum Mechanics	Lectures Tutorials	2 1	30 15	Arranged with lecturer	6
Tutorial	Tutorials	2	60	Arranged with tutor	4

Required number of credits to complete 2nd year: 30 (courses) + 30 (research project)

Courses:

Graduate School Seminar

General Seminar aiming at improving interdisciplinary background of School students.
Responsible: School management

Diploma Project

One-year project, supervised by a professor, fulfills requirements for MSc Diploma Thesis of the Jagiellonian University and most European Universities.

Elements of Quantum Mechanics

Revision of basic QM: principles, the Schrödinger equation, wave functions, and physical interpretation. Bound and continuum states in one-dimensional systems. Hydrogen atom. (joined course with other specializations)
Responsible: Prof. Andrzej Herdegen

Quantum Mechanics II

Perturbation theory. Dirac equation. Relativistic hydrogen atom. Quantum many-body theory. (part of the course may be joined with a similar course on other specializations)
Responsible: Prof. Andrzej Herdegen

Mathematical Methods and Differential Equations

Distributions, representations of Lie groups and Lie algebras, angular momentum, elementary differential equations in physics, biology, chemistry and engineering. Initial and boundary problems, discretization of differential problems. Direct and iterative solutions, Linear and nonlinear problems.
Responsible: Assoc. Prof. Andrzej Sitarz, Assoc. Prof. Zdzislaw Burda

Introduction to Electrodynamics

Maxwell equations, symmetries, equations of motions, Noether theorem, application of electrodynamics, elements of quantum electrodynamics, tests of quantum electrodynamics
Responsible: Prof. Henryk Arodź

Introduction to Field Theory

Lagrange function and action, equations of motion, symmetries, gauge theories, abelian and nonabelian gauge theories, gauge fixing, methods of quantization of field theories and gauge theories.
Responsible: Prof. Henryk Arodź, Prof. Jerzy Jurkiewicz

Geometry in Theoretical Physics

Manifolds, vector fields, differential forms, instantons and monopoles, Dirac monopole, t'Hoft-Polyakov monopole, topological defects in physics, vortices.
Responsible: Prof. Andrzej Sitarz

Introduction to Particle Physics

Basics of fundamental particles and their interactions: quark, gluons, leptons, Z,W bosons, methods of detections, electroweak and strong interactions.
Responsible: Prof. Maciej A. Nowak

Introduction to Theoretical Methods in Biophys

Introduction to the methods of theoretical physics used in biology.
Responsible: Assoc. Prof. Ewa Gudowska-Nowak

Modern Theoretical Physics Seminar

Seminar with students presentations on modern topics in theoretical physics.
Responsible: Prof. Jerzy Jurkiewicz

Introduction to Nonlinear Physics

Introduction to theoretical description of nonlinear phenomena, physical problems with nonlinear differential equations, examples. Solitons.
Responsible: Assoc. Prof. Jacek Dziarmaga

Practical Quantum Mechanics

Many body problem, dipole moment of the water molecule, relativistic quantum mechanics: the Klein paradox in many body sectors. Quantum computers: quantum mechanics of NOT and CNOT gates.
Responsible: Prof. Jacek Wosiek

Introduction to Special and General Relativity

Basic concepts, Minkowski space, Lorentz transformations, twin paradox, elementary solutions; gravity; equivalence principle applications in astrophysics, singularity theorems, Hawking radiation, gravitational waves.
Responsible: Prof. Edward Malec, Prof. Marek Kutschera

Basics of Observational Astronomy

Basis of observational astronomy: telescopes, radioastronomy, X-ray and gamma-ray astronomy.
Responsible: Prof. Edward Malec, Prof. Marek Kutschera

Astrophysics: Physics of Stars

Introduction to the theory of the evolution of stars, white dwarfs, neutron stars, supernovae.
Responsible: Prof. Edward Malec, Prof. Marek Kutschera

Cosmology: Guide to the Universe

Mathematical basics of cosmology, microwave background radiation, black holes, matter in the Universe, formation of structures, gravitational waves in cosmology
Responsible: Prof. Edward Malec, Prof. Marek Kutschera

Simulations in Physics: Monte Carlo Methods

Mathematical foundation for Monte Carlo (MC) methods; Random number generators; statistical tests. Adaptive MC techniques; MC simulation; random walks and their applications. Metropolis algorithm.
Responsible: Prof. Romuald Wit

Doing Science with Mathematica and Maple

Modeling in physics, biology, medicine and chemistry with mathematical software. Unification of computing, simulation and visualization. Examples: Chaos with a heart, synchronization processes in biology, discrete maps and chaos, binary collisions, dimensional analysis. Duffing equation, chemical oscillators, frequency analysis of time series, etc.
Responsible: Prof. Lech Longa

Computer Simulations and modeling: from theory to practice

Description: Advanced Monte Carlo Projects, Molecular Dynamics simulation (course may be joined with similar a course from other specializations)
Responsible: Assoc. Prof. Wiesław Płaczek

Econophysics - modeling of financial markets

Elements of contemporary financial markets. Time series analysis (random walks, heavy tails phenomena, GARCH and HARCH modeling) Derivatives - Black Scholes model for options, Contemporary methods of risk assessment (VaR -- Value-at-Risk) Methods of portfolios construction Genetic and adaptive algorithms, "minority game".
Responsible: Prof. Maciej A. Nowak

Time Series Analysis

Discrete Fourier Transform; Fast Fourier Transform; Shannon sampling theorem; linear filters, stochastic models AR, MA, ARMA, ARIMA; wavelets Takens embedding theorem, phase space reconstruction and nonlinear time series analysis; nonlinear prediction and denoising; statistical properties of chaotic attractors.

Details of the courses may vary. If there is no sufficient number of student in the course, the course may be canceled, joined with other courses or take a different form (seminar, with regular assignment for the students).
Responsible: Dr Paweł F. Góra