**Annotations of the courses offered by the Department of Theoretical Physics and Astronomy**

**Bachelor program**

**Methods of Mathematical Physics** (2-3dyears of study, compulsory, 6.0 ECTS credits).

Lecturer: Prof. V. M. Adamyan

The course covers an introductory minimum of tools and techniques of mathematical physics. Its first part is concerned with the Cauchy problem for linear partial differential equations on an unbounded space, and the concept of the Green's function by means of which the solutions of the Cauchy problem are reduced to quadratures. The main attention is focused on the classical and most studied heat, diffusion and wave equations. In parallel, the necessary elements of the theory of generalized functions and that of Fourier integral transformations are given.

The second part begins with an exposition of elements of calculus of variations for functionals of various types. It is followed by a consideration of typical methods, such as the Fourier method, for solving the boundary value problems of mathematical physics for systems with distributed parameters. Finally, the properties of the eigenvalues and eigenfunctions of the Sturm-Liouville boundary value problem, variational methods for their analysis, and orthogonal expansions in these eigenfunctions are discussed in detail.

**Classical Mechanics** (2-3d years of study, compulsory, 7.0 ECTS credits)

Lecturer: Assoc. Prof. V. P. Olyeynik

The course introduces to students basics of classical mechanics.

It consists of six sections:

– basic principles of Lagrangian mechanics;

– conservation laws and symmetry properties of mechanical systems;

– collisions and scattering of particles;

– small-amplitude oscillations;

– motion of the rigid body;

– Hamiltonian mechanics.

The main attention is focused on:

– introduction of basic concepts and laws of classical mechanics within the framework of the Lagrangian and Hamiltonian formulations that form the basis of modern theoretical physics;

– major methods for studying mathematical models, that give exact or approximate calculation results;

– examples of application of modern research methods to mechanical phenomena.

**Quantum Mechanics** (3-4th years of study, compulsory, 6.0-7.0 ECTS credits)

Lecturer: Prof. V. L. Kulinskii

The lecture course covers basics of nonrelativistic quantum theory (quantum mechanics, QM), including its physical foundations and necessary mathematical tools. The course consists of two parts. The first one discusses postulates of QM. Their applications are demonstrated using the simplest quantum systems (those with finite dimensional state space, like q-bit) and exactly solvable problems (H-atom and harmonic oscillator). We mainly use the operator approach built on integrals of motion and operator commutation relations.The concluding lectures of the first part cover the basic concepts of quantum information and communication (Bell’s inequalities, no-clonning theorem, Deutsch algorithm, etc). The second part deals with approximate methods and their applications to complex quantum systems: many-electron atoms and molecules, their interaction with electromagnetic field, and scattering theory. The applications of symmetry methods to the analysis of complex system spectra are also demonstrated.

**Electrodynamics** (3d year of study, compulsory, 7.0 ECTS credits)

Lecturer: Prof. M. P. Malomuzh

The students are introduced to the basics of classical electrodynamics.
The course consists of three main sections:
1) Vacuum electrodynamics;
2) Special theory of relativity;
3) Electrodynamics of continuous media.
The main attention is focused on:
1) the formulation of the physical principles of electrodynamics;
2) mastering the symmetry properties of electrodynamic phenomena;
3) the physical content of electrodynamics concepts and reasons for their introduction;
4) construction of the equations of electrodynamics in agreement with the formulated principles and properties of symmetry;
5) discussion of the connection of the results of the study of electromagnetic phenomena by Maxwell's equations with experimental results.

**Mechanics of Continuous Media** (specialty 6.040203 Physics 3d year of study, compulsory, 2.0 ECTS credits)

Lecturer: Assoc. Prof. M. Ya. Sushko

The course is intended to provide the students with knowledge, understanding, qualifications, and skills required for physical and mathematical modeling and quantitative analysis of physical processes in macroscopic systems within the continuum approximation. The course covers: basic concepts and assumptions of the continuous medium model; mathematical techniques and methods for the elaboration of mathematical models for classical systems with an infinite number of degrees of freedom; kinematic and dynamic parameters of continuous media; general laws of motion of continuous media; basics of the linear elasticity theory; basics of hydrodynamics of liquids and gasses; formulation of the boundary problems in the classical elasticity theory and hydromechanics; applications of the theory to the problems of sound propagation and hydrodynamic flows; features of physical phenomena in viscous fluids.

**Thermodynamics and Statistical Physics** (specialties 6.040203 Physics and 6.040206 Astronomy 4th year of study, compulsory, 7.0 ECTS credits)

Lecturer: Assoc. Prof. M. Ya. Sushko

The course is intended to provide the students with knowledge, understanding, qualifications, and skills required for quantitative analysis of natural phenomena and physical processes in macroscopic systems by thermodynamic and statistical methods of contemporary physics. The course covers: basic concepts, principles and laws of thermodynamics; mathematical techniques and methods for solving the basic problem of thermodynamics; basic concepts, principles and the method of Gibb’s canonical ensembles in statistical physics; types and properties of classical and quantum statistical distributions; applications of those to the analysis of heat motions in macroscopic systems, calculation of statistical averages and development of statistical thermodynamics for such systems; elements of the theory of phase transitions and critical phenomena; elements of the fluctuation theory and that of non-equilibrium processes; simplest models in condensed matter physics.

**Thermodynamics and Statistical Physics** (specialty 6.040204 Applied Physics 4th year of study, compulsory, 6.0 ECTS credits)

Lecturer: Assoc. Prof. M. Ya. Sushko

The course is intended to provide the students with knowledge, understanding, qualifications, and skills required for quantitative analysis of natural phenomena and physical processes in macroscopic systems by thermodynamic and statistical methods of contemporary physics. The course covers: basic concepts, principles and laws of thermodynamics; mathematical techniques and methods for solving the basic problem of thermodynamics; basic concepts, principles and the method of Gibb’s canonical ensembles in statistical physics; types and properties of classical and quantum statistical distributions; applications of those to the analysis of heat motions in macroscopic systems, calculation of statistical averages and development of statistical thermodynamics for such systems; elements of the theory of phase transitions and critical phenomena; elements of the fluctuation theory; simplest models in condensed matter physics.

**Advanced Topics in Quantum Mechanics** (4th year of study, optional, 4.0 ECTS credits)

Lecturer: Prof. V. M. Adamyan

The course considers some fundamental ideas and methods of quantum theory, together with their applications, that are insufficiently represented in the normative compulsory courses of theoretical physics. The course includes:

* elements of relativistic quantum mechanics, in particular, the Dirac theory and its physical consequences;
* physical consequences of the symmetries behind the physical laws in the form of fundamental equations or inherent in concrete physical objects;
* principles of quantum statistical mechanics and the method of secondary quantization;
* main concepts of the microscopic theory of superfluidity, superconductivity and those of the quantum theory of magnetism.

**Financial kinetics** (4th year of study, optional, 2.0 ECTS credits).

Lecturer: Prof. V. M. Adamyan

The course is devoted to the study of processes in financial markets on the basis of a specific synthesis, known as financial mathematics, of the methods of stochastic analysis and mathematical physics. The course introduces and examines the concepts of primary and derivative financial assets, their characteristics, basic market processes and hypotheses, and elements of the theory of financial risk. Central to this course are the problems of determining the price of derivative financial products as functions of the time and current price of the corresponding primary assets. Based on the Black-Scholes approach, it is studied how these problems can be reduced to the standard problems of mathematical physics. The course demonstrates how, using analytical and numerical methods, to value European and American options, including options for assets on dividend-paying assets, barrier options, some exotic options, options on bonds, etc., and assess the effect of commission payments on the option price.

**Business English** (2nd year of study, optional, 1.0 ECTS credits)

Lecturer: Assoc. Prof. M. Ya. Sushko

The course is intended to familiarize the students with common terminology, documentation and procedures in an English-speaking business environment, and to develop their relevant English writing and speaking skills. The topics studied include: business letter format; types of business letters; advertisements; personal data, resume and cover letter; buying, selling and sales documentation; money, financial operations and loans; transport and freight forwarding; insurance; exports and imports; Customs procedures and documentation; Incoterms.

**Selected Problems in Theoretical Physics** (4th year of study, optional, 4.0 ECTS credits)

Lecturer: Assoc. Prof. M. Ya. Sushko

The course is intended to help the students gain mastery of typical methods for solving problems from selected areas in theoretical physics, gain in-depth insight into those areas, and acquire practical mathematical skills. The course covers: posing and typical methods for solving boundary-value problems in electrodynamics and hydrodynamics; posing and methods of solving diffraction problems for electromagnetic waves; problems of electromagnetic wave propagation in guided systems; hydrodynamic flow problems. Other discussed topics include: basic properties of cylindrical functions; those of Legendre polynomials; method of integral transformations; basic properties of analytic functions; method of complex potential for 2D plane problems; method of conformal transformations.

**Quantum Field Theory** (4th year of study, optional, 2.0 ECTS credits)

Lecturer: Assoc. Prof. M. Ya. Sushko

The course is intended to help the students gain mastery of basic principles of quantum field theory and methods for quantitative analysis of quantum field interactions. The course covers: the Lagrange formalism and Neter theorem for obtaining the equations of motion of classical fields and dynamic field invariants; quantization procedure for electromagnetic field, basic characteristics of photons and photon systems; equations of motion and quantization procedure for scalar fields; Dirac equation, its main properties and quantization procedure for the Dirac field; difficulties in description of quantum field interactions and the concept of the scattering matrix; calculations methods for evaluation of the matrix elements of the scattering matrix and the Feynman diagram technique; elements of renormalization theory.

**Selected Problems in Theoretical Physics** (4th year of study, optional, 1.0 ECTS credits)

Lecturer: Prof. M. P. Malomuzh

The students are introduced to the basic methods of modern research in theoretical physics.

The course includes the following methods of "Theoretical Mechanics", "Electrodynamics" and "Quantum Mechanics"
• Determination of the equilibrium and metastable orientations of two identical charged chains and rings with fixed centers;
• Small oscillations of the segments around the equilibrium orientations from the previous task;
• Radiation of electromagnetic waves by the previous system in a vibrational state;
• Determination of the magnetic field formed by a horseshoe magnet of radiation of electromagnetic waves with a magnetic tuning fork.
• Formation of clusters by anions and cations of the same radius in two and three-dimensional spaces;
• Frequencies of the normal oscillations of dimers and tetrameters in two- and three-dimensional space spaces; the equilibrium configuration of water molecules;
• Properties of water dimers;
• Distribution of charge on the surface of a deformed sphere;
• Small oscillations of a charged sphere and the boundary of its stability.

**Theoretical Physics for Mathematicians** (3d year of study, compulsory, 4.0 ECTS credits)

Lecturer: Assoc. Prof. V. P. Olyeynik

The course provides the students of the specialization "Classical Mathematics" with a detailed introduction to the most important sections in the theoretical physics disciplines "Classical Mechanics" and "Electrodynamics", and also with basic ideas and results of the disciplines "Quantum Mechanics" and "Statistical Physics". Classical mechanics elaborates the concepts and definitions underlying modern theoretical physics. Electrodynamics is a theory of the electromagnetic field that gives us more than 95% information about the surrounding world. Quantum mechanics introduces the principles for the constructions of theoretical models of atoms and molecules. Statistical physics describes systems of many particles that obey the laws of classical or quantum physics.

**General Astronomy** (1st year of study, compulsory, 2.0 ECTS credits)

Lecturer: Prof. E. A. Panko

The course is an introduction to the cycle of astronomy disciplines. At the same time, it enables Physics majors to get acquainted with the basic ideas about the universe at different distances from the observer: from the near-Earth space to the remotest objects - quasars; and on scales from elementary particles to clusters of galaxies and voids, etc. The course includes: the apparent and true motions of celestial bodies; planets; the Sun and the Solar system; stars; galaxies; the evolution of individual elements and the Universe as a whole; and methods for studying astronomical objects. For students majoring in Astronomy, the course provides a general survey of different topics that will be scrutinized separately in subsequent courses.

**Astrophysics** (3d year of study, optional, 2.0 ECTS credits)

Lecturer: Prof. E. A. Panko

The course is intended for students who have chosen to specialize in Physics. It contains information about instruments, methods and achievements of modern astrophysics, as well as the development of the observational base and ways of storing and transferring information. The course allows future physicists to to get familiar with the variety of physical conditions observed in the Universe, including those that are unreachable in the Earth-based laboratories. Other topics addressed in detail are the physics and evolution of planets and planetary systems, stars, galaxies, relativistic objects (white dwarfs, neutron and quark stars, black holes), and the entire Universe with the influence of dark matter and dark energy taken into account.

**Magnetic Hydrodynamics** (3d year of study, optional, 2.0 ECTS credits)

Lecturer: Prof. E. A. Panko

The course (usually abbreviated MHD; also called magneto-fluid dynamics or hydro­magnetics) is intended for students who have chosen to specialize in Astronomy. Its subject is the motion of a conducting substance, such as plasma, in magnetic field. The students obtain fundamental knowledge of MHD and learn to: apply MHD methods to astrophysical processes; study stellar atmospheres and gas flows in space; calculate the configuration of the magnetic field, determine the condition of magnetic field line freezing-in; characterize the evolution of the magnetohydrodynamic medium; and determine the magnetic viscosity of the medium, the characteristic diffusion time and the rate of diffusion of the magnetic field.

**Theoretical Astrophysics** (4th year of study, optional, 3.0 ECTS credits)

Lecturer: Prof. E. A. Panko

The course is intended for students who have chosen to specialize in Astronomy. It covers classical and modern theories of the sources of stellar energy, and physical processes in the photospheres and atmospheres of stars at different evolutionary stages; features of the formation of the continuum and the appearance of absorption and emission lines; methods for determining the chemical composition of stars; studies of the internal structure of stars; and theoretical methods for investigating nebulae and interstellar matter. Students gain insight into the features of the formation of a continuum, the forms of the transfer and continuity equations and methods for their solution; the hypothesis of local thermodynamic equilibrium (LTE), its consequences and uses; models of photospheres; features of excitation and ionization of atoms, absorption and radiation; phenomena affecting the contours of spectral lines; methods of accounting for deviations from the LTE conditions; methods for determining the temperature, density and chemical composition of stellar atmospheres; the mass-luminosity- radius-chemical composition of stars theoretical relationships; sources of stellar energy at various stages of evolution; equations of the internal structure and models of stars; methods for determining the physical conditions in gaseous nebulae and interstellar medium.

**Relativistic Astrophysics** (4th year of study, optional, 2.0 ECTS credits)

Lecturer: Prof. E. A. Panko

The course is intended for Astronomy majors. It considers astronomical phenomena and celestial bodies under the conditions where the classical mechanics laws and Newton’s gravity law are inapplicable. These conditions occur when: the speed of motion is comparable to that of light; the values of pressure, energy density and gravity potential are extremely high. The students get acquainted with the processes of formation, observable manifestations, and the physics of relativistic objects with star masses, such as white dwarfs, neutron and quark stars, and black holes. The problems of the structure of these objects, the values of the limiting masses for white dwarfs and neutron stars and the evolution of these objects in binary systems are discussed in detail.

**Computational methods** (1st year of study, compulsory, 2.0 ECTS credits)

Lecturer: Assoc. Prof. O.A. Bazey

The course contains the following topics:

• Smoothing, approximation and linearization of functions.

• Least square method.

• Interpolation of table-defined functions:

Lagrange polynomial, Newton polynomial, Stirling polynomial, Bessel polynomial.

Differentiation according to the table.

• Numerical solution of equations: the method of dichotomy, simple iterations, Newton.

• Finding the minimum of the function: the method of the golden section, the method of parabolas.

• Numerical methods for the determination of a Riemann integral: the Monte Carlo method, trapezoids, rectangles, Simpson.

• Numerical solution of ordinary differential equations: Euler's method, forecasting and correction method, Runge-Kutta methods.

• Expansion of functions in a Fourier series.

Necessary preliminary knowledge and skills: a course of mathematical analysis, basic computer skills, use of electronic form of communication.

**General Astrometry** (2nd year of study, optional, 6.0 ECTS credits)

Lecturer: Assoc. Prof. O.A. Bazey

The course contains the following topics:

• The heavenly sphere.

• Coordinate systems on the celestial sphere.

• Relationship between coordinate systems.

• Coordinates on the Earth's surface.

• Timing systems.

• Measure large time intervals.

• The diurnal rotation of the celestial sphere.

• Astronomical refraction.

• Aberration: daily, annual, planetary.

• Parallax: daily and yearly. Own movement of the stars.

• Precession and nutation.

• Reduction of observations. Bringing to the visible, true and average place.

• Problems of establishing an inertial coordinate system.

• Implementation of the inertial coordinate system. The fundamental system of celestial coordinates.

• The meridian method for determining the celestial coordinates. Absolute and relative methods of determining coordinates.

• Photographic method for determining the celestial coordinates. Turner's method.

• Star catalogs.

Necessary preliminary knowledge and skills: course in general astronomy course of mathematical analysis, general physics course, basic computer skills, the use of electronic forms of communication.

**Celestial Mechanics** (3d year of study, optional, 8.0 ECTS credits)

Lecturer: Assoc. Prof. O.A. Bazey

The course contains the following topics:

• Task N bodies. Integrals of conservation.

• The task of 2 bodies. Equation of trajectory. Classification of motions in the problem of two bodies. Refined Kepler Law.

• Orbital elements. Calculation of the position of the celestial body in an elliptical orbit. The Kepler equation.

• Calculation of the position of the celestial body in infinite orbits.

• The limited three-body problem. Equation of motion. The Jacobi integral.

• The surfaces of Hill. Singular points of Hill surfaces. The Lagrange points. The Tisseran criterion.

• Calculation of orbital elements. The Gauss method. Vaisala's method of calculating the elements of a circular orbit. Olbers method of computing elements of a parabolic orbit.

• The problem of the relative motion of N bodies. Lagrange Equations. Indignant movement. Non-gravitational perturbations.

Necessary preliminary knowledge and skills: the course of general astronomy, the course of mathematical analysis, the course of calculation methods, the course of differential equations, the course of classical mechanics, basic computer skills, the use of electronic forms of communication.

**Radioastronomy and Stellar Astronomy** (4th year of study, optional, 3.0 and 3.5 ECTS credits)

Lecturer: Assoc. Prof. V.I. Marsakova and B. A. Murnikov

The course combines topics concerning, for the most part, large-scale cosmic processes and phenomena. The students get mastery of radio astronomy and stellar-statistical methods of studying the Universe. The first part of the course considers the research methods and results in radio astronomy including the emergence and role of radio astronomy in astrophysics; basic concepts of radio astronomy; the temperature and flux density of radiation; polarization of radio emission; types of radio telescopes and antennas; aperture synthesis; radio emission mechanisms; spectra of radio sources; radio astronomy of the Solar system; galactic and extragalactic radio astronomy. The second part analyzes the structure and evolution of our Galaxy based upon the characteristics of its typical objects, such as stars, star clusters and interstellar gas; methods for determining the distances to these objects, their kinematic characteristics, masses, etc.; and methods for physical modeling of the structure and motion of stellar systems.

**Physical Variables and Binary Stars** (4th year of study, optional, 2 ECTS credits)

Lecturer: Assoc. Prof. V.I. Marsakova

The course introduces to students the problems in the studies of physical variables and binary stars. It discusses the connection between these studies and such problems as determining distances in the Universe; finding physical characteristics of stars; developing stellar evolution theories and exploring exoplanets, star clusters, and galaxies. Modern methods of research, observations, and observation data processing, as well as principles and methods of classification of physical and binary stars are also considered. The students acquire practical skills in making observations of variable stars, processing the observation data obtained and using the observation data from automatic sky surveys and international databases. They also learn to distinguish between the most common types of variable stars based on their light curves; calculate some physical parameters of pulsating stars and double star systems; and evaluate some evolutionary characteristics of close, interacting binary stars.

**Multicolor Photometry** (4th year of study, optional, 1.5 ECTS credits)

Lecturer: Assoc. Prof. V.I. Marsakova

The course discusses the study of space objects by observations of them in various spectral bands with different radiation detectors. Its main objective is to teach the students to reconstruct the energy distribution in a star’s (or another radiating cosmic object’s) spectrum by multicolor photometric observations. The course considers the spectral sensitivity curves of various photometric instruments; types of photometric systems and their characteristics; distortions of the spectral energy distribution due to interstellar absorption, atmospheric effects, and the influence of the optical system; and correction methods for taking these effects into account. The students also study the energy distribution curves in the black-body spectrum and the causes behind the deviations from this distribution in the spectra of real stars and other space objects. Finally, the students learn to use photometric values describing the radiation of celestial bodies; determine the temperature and other characteristics using multicolored photometric observations, and transform observation data to standard photometric systems.

**Special Functions** (3d year of study, optional, 3 ECTS credits)

Lecturer: Assoc. Prof. V.I. Marsakova

The course deals with different types of special functions used in different problems of astronomy and physics. The emphasis is on the gamma functions that often appear in various statistical problems, the spherical functions that widely arise in calculations of the motion of near-the-Earth objects and in many other fields of astrophysics as well; and some others functions. We consider the properties of these special functions, the features of the expansions of functions in series of them, and examples of their applications.

**Designing Extremal Experiments** (3d year of study, optional, 1 ECTS credit)

Lecturer: Assoc. Prof. V.I. Marsakova

This course helps the students deepen their knowledge of mathematical statistics and processing the results of experiments (observations). Students are introduced to the methods of designing experiments aimed at achieving the desired results quickly, and develop their skills in statistical data processing and posing experiments (observations).

**General Astrophysics** (3d year of study, optional, 9.0 ECTS credits)

Lecturer: Senior Lecturer B. A. Murnikov

Astrophysics is the largest branch of modern astronomy. Due to a huge amount of the material involved, theoretical problems are studied in the course of Theoretical Astrophysics. All the other topics are considered in the course of General Astrophysics. It studies: physical principles and main methods of astrophysics; the structure and functions of telescopes; the function and design of radiation detectors; features of spectral and radio-astronomy devices; general information about the Sun, the structure and evolution of celestial bodies of the solar system; physical parameters and evolution of stars; the structure and evolution of the interstellar medium, stellar systems, and the Universe as a whole. The students also learn to identify the stars on astronomical negatives; execute visual photometrical observations of stars on astroplates; recalculate the magnitudes from one photometric system to another; determine the wavelengths in the spectra of celestial bodies, determine the spectral classes of stars; explain the essence of the basic physical processes in celestial bodies; and resolve other astrophysical tasks.

**Astronomy Practicals** (3d year of study, optional, in the 7th semester is 6.0 ECTS credits, in the 8th semester 5.0 ECTS credits)

Lecturer: Senior Lecturer B. A. Murnikov

The course helps the students gain practical skills in processing astronomical observations. In particular, they learn to determine the dynamic parallaxes of stars; determine elements of the orbit of visual and spectral binary stars; take into account the absorption of light in the Earth's atmosphere and determine the extinction coefficient; calculate the radial velocities of stars and take into account the effect of the Earth’s motion on them; calculate the energy distribution in stars’ spectra; process radio-astronomical observations; use CCD cameras for observations; to execute preprocessing of CCD frames; use modern software packages to determine the magnitudes of stars and the light curves of variable stars; analyze the spectra of stars of different spectral classes; determine the accuracy of observational data; and use programs to visualize the sky view.

**Introduction in Spectroscopy** (4th year of study, optional, 2.5 ECTS credits)

Lecturer: Senior Lecturer B. A. Murnikov

The course is devoted to the operation principles of spectral devices used in astrophysics. It covers the following topics: spectrum formation; basic characteristics of spectral devices, including the photometric characteristics; light refraction in a prism; types of prism instruments; the principles of diffraction gratings and setup of diffraction instruments; purpose and operation principles of astronomical instruments of high resolution. The students learn to calculate the beam path in a prismatic device; the diffraction patterns produces by a single slit and several slits; and the diffraction grating profile with the concentration of light of a given order.

**Master program**

**Basics of Physics of Superconductivity** (optional, 1.0 ECTS credit)

Lecturer: Prof. V. L. Kulinskii

This course covers the basics of low-temperature superconductivity theory. The progress in understanding the nature of this phenomenon is shown chronologically. The emphasis is to show how key experimental discoveries (Meissner–Ochsenfeld effect, thermodynamic behavior of the entropy and heat capacity, magnetic flux quantization, isotopic effect, etc.) lent impetus to the development of the theory, starting from the electrodynamic Londons’ model and phenomenological Ψ- theory by Ginsburg and Landau. At the end of the course, the basics of the microscopic Bardeen-Cooper-Schrieffer (BCS) theory are presented. The course is arranged so as to show the students how the basic laws familiar to them from Electrodynamics, Quantum Mechanics, Thermodynamics, and Statistical Physics are at work in the phenomenon of superconductivity.

**Computer Modeling of Physical Processes (using the Wolfram Mathematica Environment)** (compulsory, 4.0 ECTS credits)

Lecturer: Prof. V. L. Kulinskii

The course is intended to help the students gain practical skills in analysis of physical processes through computer simulation. The main tool is the Wolfram Mathematica environment which is used to demonstrate basic algorithms and numerical methods (finite differences, Bubnov-Galerkin, FEM, etc.). It also provides a multifunctional interface for the presentation of the research results (by generating reports, papers and slide-shows). The students have an opportunity to restore the solutions of problems from previously taken courses of Methods of Mathematical Physics, Electrodynamics, Quantum Mechanics and others using computer models and visualization of the results.

**Nonequilibrium Statistical Thermodynamics** (optional, 4.0 ECTS credits)

Lecturer: Prof. V. L. Kulinskii

The course gives an introduction to the theory of stochastic processes and its applications to the problems of nonequilibrium statistical physics. The emphasis is on the methods of constructing and solving the kinetic (master) equation. The hierarchy and interrelation between basic Markovian processes (Wiener process, Ornstein-Uhlenbeck process, and white noise) are demonstrated with an example of random walk. The other topics discussed are Kubo’s linear response theory (for both classical and quantum cases); the fluctuation-dissipation theorem; and basic properties and applications of Green’s functions to calculation of the kinetic characteristics of systems.

**Selected Problems in Statistical Physics and Quantum Field Theory** (optional, 2.0 ECTS credits)

The course introduces the diagrammatic technique for the Ising model (IM). Onsager’s exact solution for the IM by the transfer-matrix method, and the fermion representation of the IM It also discusses the conformal symmetry of critical fluctuations correlation functions. The course demonstrates a close connection between problems in statistical mechanics and quantum field theory.

**Theory of Elementary Particles** (optional, 4.5 ECTS credits)

Lecturer: Assoc. Prof. M. Ya. Sushko

The course is intended to provide the students with knowledge, understanding, qualifications, and skills required for quantitative description of fundamental structure units of matter and interactions between those based upon gauge theories and spontaneous violation of local gauge invariance. The course cover: major results of the early period in the elementary particle physics studies; modern notions on the fundamental structure elements of matter, on their characteristics and hierarchy; main characteristics and symmetry properties of strong interaction; structure models of hadrons; concepts of local gauge invariance and Yang–Mills gauge fields; basic principles of quantum chromodynamics; main characteristics and symmetry properties of weak interaction; principle of spontaneous symmetry violation and the Higgs mechanism for particle mass generation; basic principles of the Weinberg–Salamstandard model for electroweak interaction.

**Physics of Water and Water Solutions of Biomolecules** (compulsory, 3.0 ECTS credits)

Lecturer: Prof. M. P. Malomuzh

The students are introduced to the main results of modern research on the physics of water and the role of water in the emergence and maintenance of warm-blooded life.

The course discusses: basic thermodynamic and kinetic properties of water and behavior of water in electric and magnetic fields; the physical nature of intermolecular interaction in water, in particular, the modern view of the nature of hydrogen bonds; the features of the microstructure of water generated by clustering processes of molecules; specific changes in the properties of water with temperature;
the properties of water which play a key role in the emergence of life on the Earth and its support and development; the physical origin of the boundaries of existence of living matter, mechanisms for the self-regulation of the working temperature of different organs and the degree of acidity of the working environment.

**Physical Hydrodynamics** (optional, 3.0 ECTS credits)

Lecturer: Prof. M. P. Malomuzh

The students are introduced to the main results of the theory of thermal hydrodynamic fluctuations and its applications to the problems of molecular dynamics.

The course discusses: the equations of hydrodynamics; methods of constructing the correlation functions of the Eulerian and Lagrangian variables of hydrodynamics; properties of the autocorrelation velocity function of water molecules; features of the components – chaotic local mixing of molecules and collective transfer – of the self-diffusion coefficient of water molecules; specificity of the components of self-diffusion of argon and water molecules, in particular, the nature of their temperature dependence on the coexistence curve; manifestation of the two most important constituents of the transport of liquid molecules in the behavior of the mean square displacement of the molecule of water in computer experiments; incoherent scattering of slow neutrons, dielectric relaxation, etc.

**Special Topics in Quantum Theory of Solids** (compulsory, 2.0 ECTS credits)

Lecturer: Prof. V. M. Adamyan

This discipline studies questions and special models of the quantum theory of solids that form the theoretical basis of nanoelectronics and spintronics.

The topics encompassed are:

• features of electronic transport in nanodevices, in particular, the ballistic and diffusion modes of conductivity; quantum interference, thermal and thermoelectric effects in nanowires and nanocircuits;

calculations of transport characteristics of nanoconductors and quantum interference nano field-effect transistors;

• densities of electronic and phonon states in nanoconductors and semiconductors, in particular, in graphene and carbon nanotubes;

• giant magnetoresistance in nanoscale heterostructures;

• the concepts of spin diffusion and spin current;

• spin valves and spin transistors based on the effect of electro-spin modulation.

**Quantum Informatics** (compulsory, 4.0 ECTS credits)

Lecturer: Prof. V. M. Adamyan

The course considers the basic principles of quantum informatics and quantum algorithms that have been firmly entrenched in computer science for the past twenty years and now constitute the foundation for further development of information technologies based on quantum logic circuits and algorithms. It addresses:

• features of the states of the quantum analog of the classical bit - qubits and states of quantum registers of several qubits;

• specificity of measuring the states of qubits and registers;

• features of the operators performing the transformation of qubit states and limits on quantum manipulations, in particular, the non-cloning theorem;

• effective quantum algorithms, including those of Deutsch-Josza, Grover, Simon, and Shor;

• elements of quantum cryptography and protocols for safe transmission of information through quantum communication channels;

 • related issues: the Einstein-Podolsky-Rosen paradox and the Bell inequality;

 • ways of physical implementation of quantum algorithms.

**Statistical Thermodynamics of Irreversible Processes** (optional, 4.5 ECTS credits)

Lecturer: Prof. M. P. Malomuzh

The course introduces to students basics of nonequilibrium thermodynamics.

It covers: the formation of basic concepts of the thermodynamics of irreversible processes; the local structure of conservation laws and the principles of constructing equations of hydrodynamics; the definition of thermodynamic forces and flows; the production of entropy; the definition of kinetic coefficients and the formulation of the Onsager principle of symmetry for them; the basics of the Kubo theory of linear response; the relation of the kinetic coefficients to the correlation functions for flows; hydrodynamics equation of nonideal liquid; symmetry requirements for the stress tensor; linearized form of the hydrodynamics equations; longitudinal and vortex excitations; propagation of sound in liquids and gases and the decrement of its damping; surface waves: gravitational, capillary and Rayleigh waves; hydrodynamics of binary solutions and the peculiarities of sound and heat propagation in them, role of the internal degrees of freedom; hydrodynamics of liquid crystals and suspensions.

**The Theory of Phase Transitions** (optional, 2.0 ECTS credits)

Lecturer: Prof. M. P. Malomuzh

This special course introduces to students the basics of the physics of phase transitions of the first and second kinds.

The main focus is on:
1) the formulation of the basic concepts of the theory of phase transitions;
2) inspection of the basics of the thermodynamic theory of phase transitions;
3) the Landau theory of phase transitions of the second kind;
4) construction of the basis for the fluctuation theory of phase transitions and the Ginzburg-Landau Hamiltonian;
5) familiarizing the students with the scale and conformal symmetry of fluctuations;
6) construction of the basis of the renormalization method;
7) calculation of the critical parameters using the perturbation theory;
8) the equation of state of a system in the vicinity of the critical point, the canonical parameter of order, and the canonical formalism for the description of critical phenomena.

**Forms of Presentation of Scientific Research** (compulsory, 5.0 ECTS credits)

Lecturer: Assoc. Prof. V. P. Olyeynik

The course consists of four sections:

1. General characteristics of scientific research; features of applied and fundamental physical researches.

2. The ethics of scientific research: academic integrity; respect for copyright and fight against academic dishonesty (plagiarism); measures to prevent plagiarism.

3. Preparation of scientific research materials for presentation: working with documentary sources of information; compiling a list of bibliographic sources, writing a research manuscript with own scientific results; designing the illustrative material.

4. Different type reports and specific features of their presentation: oral and written conference reports; a scientific journal article or a brief report (letter to the editor); a popular science article; a request to the Ministry of Education of Ukraine for a research grant. The specific features of preparing Master's, Ph.D., and Dr. Sc. theses for defense are also discussed in detail.

**Theory of Gravitation** (optional, 3 ECTS credits)

Lecturer: Assoc. Prof. V. P. Olyeynik

The course introduces to students basics of the modern theory of gravitation.

The topics discussed include:

– mathematical foundations of the theory (algebraic and differential properties of tensor quantities; the Christoffel-Riemann curvature tensor and its properties; the eigenvalue problem for the Weyl tensor and the Petrov-Penrose classification);

– basic principles of Einstein’s theory of gravitation (General Relativity, GR), the gravitational field equations in GR, and the nonrelativistic limit in GR;

– the spherically symmetric gravitational field in empty space (the Schwarzschild solution), Birkhoff's theorem and its corollaries, and black holes;

– the cosmological models of Einstein and de Sitter, Friedman models, Standard model of Gamow’s hot universe, inflation models, and problems in the theory of the early universe evolution;

– observational tests of the theory of gravitation, gravitational waves, most important astrophysical objects in the observable universe, dark matter in galaxies and clusters of galaxies, and dark energy in cosmology;

– the properties of space-time and gravitational theories, theory of gravity and elementary particles, and problems of a unified field theory (the theory of everything).

**Relativistic Astrophysics** (optional, 3.0 ECTS credits)

Lecturer: Prof. E. A. Panko

The course is intended for Astronomy majors. It considers astronomical phenomena and celestial bodies under the conditions where the classical mechanics laws and Newton’s gravity law are inapplicable. These conditions occur when: the speed of motion is comparable to that of light; cosmological distances, the values of pressure, energy density and gravity potential are extremely high. The students get acquainted with astronomical methods of testing the General Relativity Theory (GTR) and applications of GRT methods to the study of the Universe, its formation and further evolution, with the influence of dark matter and dark energy taken in to account (Λ*CDM* model).

**Extragalactic astronomy** (optional, 2.5 ECTS credits)

Lecturer: Prof. E. A. Panko

The course is intended for masters who have chosen "astronomy" as the specialization. The main topics of the course – the largest elements of the universe and their observed state are the experimental basis of modern cosmology. The course consists of two connected parts. In the first part, galaxies, their structure, morphology features, the evolution of morphological types in the cosmological time scale are studied, In the second one, larger structures of Universe are studied beginning from the Local Group of Galaxies to the elements of the large-scale structure of the Universe, namely clusters and superclusters of galaxies, their basic elements and morphology, as well as filaments, galactic walls and voids.

**Physics of the Interstellar Medium** (optional, 3.0 ECTS credits)

Lecturer: Prof. E. A. Panko

The course is intended for students who have chosen the specialization "astronomy". It studies astronomical phenomena and properties of the interstellar medium (ISM) - the matter, fields and radiation that exists in the space between the stars and star systems in a galaxies. The ISM and the process in it are extremely important at the initial and final stages of the evolution of stars. The topics of the course includes the structure of the Galaxy and a general description of the ISM; its composition (atomic, molecular and dust components of ISM, as well as the electromagnet field) and the interaction of individual components, electromagnetic radiation of ISM, thermal and nonthermal, physical processes in conditions of extremely low temperatures and densities; the interaction of stars and their shells with ISM, gas-dust complexes, regions of star formation, the initial stages of stellar evolution.

**Dynamics of the Solar System** (optional, 3 ECTS credits)

Lecturer: Assoc. Prof. O.A. Bazey

The course contains the following topics:

• Kepler's laws as a consequence of Newton's laws. The "law" of Titius-Bode.

• The structure of satellite systems of giant planets.

• The system of satellites of Jupiter. The Saturn Satellite System. Systems of satellites of Uranus and Neptune.

• The structure of the main belt of asteroids. Luke Kirkwood. Motion in resonance.

• The general problem of 2 and 3 bodies. Optimization of calculations.

• Decomposition in elliptical motion. Barycentric orbits.

• Planetoid task of 3 bodies. Equations of motion. Libration points and their stability. Asteroids and satellites-Trojans.

• Potential theory. Tidal deformation. Internal structure of the satellites of the planets. Zone of Rosh. Tidal moments of strength. Tidal evolution.

Necessary preliminary knowledge and skills: the course of mathematical analysis, the course of differential equations, the course of celestial mechanics, basic computer skills.

**Astrodynamics** (optional, 3 ECTS credits)

Lecturer: Assoc. Prof. O.A. Bazey

The course contains the following topics:

• Jet propulsion. Meshchersky's equation. The first formula of Tsiolkovsky. The structure of the rocket. Characteristic speed.

• Exit to the free flight path. The second formula is Tsiolkovsky. Gravitational losses. Aerodynamic losses. Losses on management. Favorable factors of missile launch.

• Movement in near-Earth space. Determination and selection of the orbit. Use of the main results of the solution of the two-body problem for the determination of motion in near-earth space. Geocentric motion. Putting into orbit. Weightlessness. Surface forces.

• Movement of the satellite relative to the earth's surface. The shape of the Earth's surface. The route of the satellite. Trails of low, polar and equatorial satellites. Routes of geosynchronous and geostationary satellites. Perturbations of the motion of the satellite. Descent from orbit.

• Movement in the circumsolar space. The sphere of influence of planets and the approximate method of calculating the trajectory of an interplanetary flight.

• Relative gravitational perturbations. Scope of the planet. Hill's sphere. The sphere of gravity of the planet.

• Features of interplanetary flight. Movement in the sphere of action of the Earth. Heliocentric motion outside the Earth's sphere of action. The Gomanov trajectory. Movement in the sphere of the planet-goal.

• Gravitational maneuver in the gravitational field of large planets. The conditions for the approach of the spacecraft to outer and inner planets. Change in mechanical quantities during the gravitational maneuver. The angle of the turn of the speed. Passive and active gravitational maneuver.

Necessary preliminary knowledge and skills: the course of mathematical analysis, the course of differential equations, the course of celestial mechanics, basic computer skills.

**Methods of teaching astronomy** (compulsory, 1 ECTS credit)

Lecturer: Assoc. Prof. O.A. Bazey

The course contains the following topics:

• The general educational value of astronomy. Naturally scientific; world outlook; culturological and historical; universal and practical significance of astronomy.

• Means of teaching astronomy and the distribution of hours.

a) Lectures; seminars; practical work; laboratory; training and production practices.

b) Curriculum; lecture notes; visual demonstrations; hometasks; preparation for seminars, training and production practices.

• Lecture as the main means of obtaining knowledge by the student. General preparation of the teacher for the lecture; logical harmony of the lecture; history of the lecture theme; introduction of basic concepts; structuring of lectures.

A variety of lectures.

a) Lecture for students of different courses. General astronomy course (KOA) - lecture on the 1st course (structure, concepts, formulas); check the understanding of the material of previous lectures (at the lecture); lecture depending on the nature of the subject (general courses); lecture on senior courses (special courses and interaction with the audience); Formulas and their analysis using mathematical preparation.

b) Other properties of lectures in higher educational institutions. Organizing skills of the lecture; interdisciplinary relations; educational skills; induction of methodological skills; a clear example of the preparation of the lecture.

• Practical exercises, as a basis for mastering lecture material. Purpose of practical classes and differences from lecture courses; features of practical exercises; methods for preparing for practical classes; the structure of tasks and reporting; control of the fulfillment of tasks.

Necessary preliminary knowledge and skills: general astronomy course, mathematical analysis course, general physics course, basic computer skills.

**Multiple Stellar and Planetary Systems** (optional, 4 ECTS credits)

Lecturer: Assoc. Prof. V.I. Marsakova

The course is an in-depth extension of the B.S. program course “Physical variables and double stars” to the field of multiple star systems and stars (systems of stars) with planets. The course discusses similarities and differences between research methods for stellar systems and planetary systems around other stars; modeling methods for obtaining the geometric and physical characteristics of these systems; features of the evolution of multiple stellar and planetary systems and their relation to the problems of single (in particular, chemically peculiar) star evolution theories; and the development of cosmogony of planetary systems in the context of the modern discoveries of exoplanets. The main attention is focused on providing the students with practical skills in estimating the parameters of multiple systems by using the data obtained by various astrophysical methods, including modern software codes.

**Theory of Similarity** (optional, 4 ECTS credits)

Lecturer: Assoc. Prof. V.I. Marsakova

The course discusses the methodology of the similarity theory and dimensional analysis, as well as the applicability of these methods in various branches of astrophysics, such as planetary astrophysics, star astrophysics, high-energy astrophysics, and cosmology.

**Nuclear Astrophysics** (optional, 2.5 ECTS credits)

Lecturer: Senior Lecturer B. A. Murnikov

Nuclear astrophysics is one of the youngest branches of modern astronomy. It has made great strides in explaining the physical nature and evolution of stars and other objects. The course introduces to students the thermonuclear reactions occurring in stars of different types; the reaction of thermal neutron capture; and the chemical evolution of our Galaxy, in particular, and the Universe as a whole. It also covers in detail the proton-proton cycle and CNO cycle reactions; hot-cycle (Ne-Na, Mg-Al) reactions; thermonuclear synthesis in supernovae; processes of capture of slow neutrons; peculiarities of the chemical composition of stars of different types and features of the chemical evolution our Galaxy and the Universe as a whole.

**Geo- and Space-Physics** (optional, 5.0 ECTS credits)

Lecturer: Senior Lecturer B. A. Murnikov

Geophysics studies the physical processes in the Earth and its atmosphere. Since our planet is not isolated in the Universe, geophysics and the physics of the near-Earth space environment are closely related. The students study the methods of geophysical research, the physical characteristics of the Earth, its internal structure, its outer shells and physical fields, and its interconnection with other bodies and fields in the solar system. The course includes the topics concerning the Earth-Moon system, gravimetry, seismology, geochronology, geomagnetism, meteorology, oceanology, the physics of the Moon, that of the planets of the solar system and interplanetary space, and that of solar-terrestrial connections. The students learn to locate the epicenter and focus of an earthquake; determine the earthquake shock energy, calculate the age of rocks using the ratios of radioactive isotopes; determine the components of the Earth's magnetic field in terms of its tension, declination and inclination; calculate the temperature at different depths using the geothermal gradients; and solve other problems.