PhD School of Physics

Discipline: Science
Form of education: Doctor of Philosophy (PhD) training
Objectives: acquire the academic degree training and the skills necessary in research, development, innovation, and higher-level education
Length of training: 8 semesters
Training type: regular school
Financing: state-sponsored or tuition-fee based
Entrance requirements: MSc and a successful entrance exam
Language requirements: a type „C" secondary (or equivalent) language exam (preferrable in English) recognized by the state (entrance requirement) and a basic level second language exam (exit requirement)
Training phases: First two years (period I): 120 ECTS credits, finished with a complex exam
Last two years (period II): 120 ECTS credits, finished with an absolutorium
Number of ECTS credits required: 240
Moduls of ECTS credits:
Progams I-III: study credits (48), research credits in the first two years (72), in the last two years (120)
Program IV (Physics education): study credits (80), research credits in the first two years (52), in the last two years (120)

Person responsible for the training: Dr. Jenő Gubicza, professor of physics, head of the PhD school

Faculty responsible for the training: Faculty of Science

Training modul

Program I: Materials Science and Solid State Physics

Head of the program: Dr. István Groma

Course descriptions

(all optional classroom courses for 6 credits, cannot be repeated, credits to be obtained: 48)

Properties of nanostructural materials

FIZ/1/001 Nanophase metals

- Introduction to, classification of and interest in (metallic) nanophases
- Preparation, structure and thermal stability of metallic nanophases
- Magnetic properties of nanoscale particles, bulk nanocrystalline metals and nanophase composites
- Magnetic properties of nanoscale films and multilayers (magnetic anisotropy, exchange coupling)
- Electrical transport in nanoscale films, multilayers and nanocrystalline metals

Electrical transport in metallic magnetic nanostructures in external magnetic field (giant magnetoresistance = GMR)

FIZ/1/009 Micro- and nanotechnology I.

General characterization of nanotechnology; properties of individual nanoparticles; metal and semiconductor nanoclusters; quantum properties of one, two and three dimensional nanoformations; production methods of nanoparticles; self-organization; investigation methods of nanostructures; carbon nanostructures; nanostructural bulk materials; unordered nanostructural materials, multilayers, composite materials, nanocrystals, colloid systems, photonic crystals, magnetic properties of nanostructural materials; optical properties of nanostructural materials; biological nanostructures; applications of nanostructures; the potential of nanotechnology, aspects in environmental protection, health and ethics

FIZ/1/044 Micro and nanotechnology II.

Optical properties of nanoparticles, photonic crystals, magnetic properties of nanostructures, biological nanostructures, nanomechanics, chemical synthesis of nanoparticles, nanoparticles for drug delivery, applications of nanostructures, potential benefits of nanotechnology, ethical, medical and environmental aspects

FIZ/1/032 Nanomagnetism

The origin of the materials' magnetic properties: magnetic moments, exchange interaction (direct, super, RKKY), magnetic anisotropy. Measurement methods: bulk and local magnetic properties. Magnetic structures: ferromagnetism, anti-ferromagnetism, ferrimagnetism, helimagnetism, spin glasses, superparamagnetism. Magnetic materials: conventional soft and hard permanent magnetic materials, amorphous and nano-crystalline magnets, thin layers and multilayers, nano composites, magnetic semiconductors. Magnetic phenomena in nano-structured materials, spintronics.

FIZ/1/040 Bulk nanostructured materials

1. Bulk ultrafine-grained and nanocrystalline materials
2. Processing of bulk ultrafine-grained metals and alloys by powder metallurgy
3. Processing of bulk UFG materials by severe plastic deformation
4. Nanocrystallization of bulk metallic glasses

5. Nanocomposites
6. Nanoporous materials

Phenomenological theories of different materials

FIZ/1/004 The finite element method and applications in material science

This course introduces the finite element method, as a numerical method to find approximate solutions to boundary condition problems. The following main topics are involved:

- variational methods of plasticity theory
- the stiffness matrix and stiffness equation
- principal aspects of the theory of interpolation
- numerical integration
- technical aspects of solving equation system containing sparse matrices
- nonlinear problems (nonlinearity in geometry, material and boundary conditions)
- evaluate the error of the simulations
- applications: elastic and plastic formation, problems in fluid mechanics and electromagnetism

FIZ/1/005 Liquid crystals, polymers

1. Introduction: mesomorphic behavior, mesogens, characterization of liquid crystal phases.
2. Statistical theories: mean field theory, Landau-, Onsager-, and Maier-Saupe theories, description of phase transitions, order parameter.
3. Methods in molecular dynamics: dielectric spectroscopy, NMR, neutron diffraction.
4. Continuum description of the nematic and cholesteric liquid crystals: deformational free energy, effects of external fields, surface interactions, Fréedericksz transition, field effects in cholesterics.
5. Continuum theory of Ericksen-Leslie: equilibrium equations, material equations, reversible and irreversible processes, viscosity measurement, Lehmann-effect.
6. Optics of liquid crystals: polarized light, birefringence, selective reflection, optical rotation, adiabatic light propagation, dichroism, realigning by light, thermal-optics, creation of higher harmonics.
7. Ferro-electric liquid crystals: polarization, flexoelectricity, spontaneous polarization and its measurement, chiral smectic C* phase, SmA*-SmC phase-transition, Landau-theory, ferroelectric switching, electromechanical effects, antiferroelectric phase, banana liquid crystals, electroclinic effect.
8. Piro-, flexo- and ferroelectricity
9. Liotropic liquid crystals, membranes, double layers, biological aspects
10. Liquid crystal polymers

    Application of liquid crystals: heat mapping, structure of a display, display effects, matrix displays, color display, light controlled devices

FIZ/1/006 Pattern formation in complex systems

- Introduction, definitions: evolution of spatio-temporal patterns in systems far from equilibrium
- Homogeneous, ordered (periodic) and chaotic states
- Theoretical description: methods, dissipative dynamics, stability and bifurcation, linear stability analysis and nonlinear basic states, model equations
- Nonlinear behavior in classical mechanical physics
- Nonlinear behavior in chemistry (Bjelousov-Zhabotinsky and Turing instability)
- Fluid flow (shear) instability: Taylor-Couette, Rayleigh, Rayleigh-Taylor, Kelvin-Helmholtz instabilities.
- Thermal convection: Rayleigh-Benard and Benard-Marangoni instability

- The role of anisotropy: thermal convection in liquid crystals
- Electroconvection
- Surface patterns: viscous fingers, linear stability analysis
- Non-equilibrium solidification: dynamics of the solid-liquid interface
- Non-Newtonian fluids
- Computational methods: DLA, phase-field model, sharp boundary model
- Experimental technics: “shadowgraph”, image processing, PIV, particle tracking
- Instability in granular materials

FIZ/1/008 Computational materials science

Cellular automata, simulating liquid flow by cellular automaton, the basis of molecular dynamics, usage of pair potential, the basis of quantum mechanical many-particle potential, calculations based on first principles, thermostat and pressure tank in molecular dynamics, the basis of phase field theories and their application in systems with precipitations, dislocation dynamics, continuum theory of dislocations

Physical bases of material sciences

FIZ/1/015 Physical materials science I

Molecular dynamics, Empirical potential, barostats, thermostats, Finnis-Sinclair potential, First principle calculations, vacancies, diffusion, Cahn–Hilliard equation, Phase rule, thermodynamics of multicomponent materials, Phase field theories, Superalloys, Field theory of dislocations, Statistical physics of dislocations, dislocation patterning

FIZ/1/018 Nuclear solid state physics I

- Electric and magnetic moments of nuclei. Electromagnetic decay of nuclear states.
- Radiation detectors. Hyperfine interaction and its information on the structure of materials.
- Mössbauer effect. Components of the hyperfine interaction in Mössbauer spectra. Mössbauer spectroscopy with radioactive sources. Mossbauer spectroscopy using synchrotron radiation.
- Gamma-gamma perturbed angular correlation: time-differential and time-integral methods. Perturbed angular distribution of gamma rays.
- Nuclear magnetic resonance. Nuclear spin relaxation, Bloch equations. Chemical shift, Knight shift. Nuclear magnetic resonance using radioactive nuclei.
- Muon spin rotation. Muon spin relaxation.

FIZ/1/019 Nuclear solid state physics II

- Positron annihilation. Trapping of positrons in lattice defects.
- Basics of neutron scattering. Neutron sources. Neutron diffraction. Magnetic structure analysis by neutron diffraction. Small-angle neutron scattering. Quasielastic neutron scattering. Inelastic neutron scattering. Neutron backscattering. Neutron spin echo.
- Ion accelerators, ion detectors. Rutherford backscattering. Channeling. Lattice localization by channeling. Elastic recoil detection spectroscopy. Nuclear reaction analysis.

FIZ/1/024 Lattice defects I.
Point defects, diffusion, Dislocations and plastic deformation, Mechanical properties, Stacking and twin faults in face-centered and body-centered cubic crystals, Twinning in hexagonal crystals, Solid solution hardening, Recovery and recrystallization

FIZ/1/025 Lattice defects II.
Interaction between dislocations and secondary phase particles, Geometric models of grain boundaries, Physical models of grain boundaries, Grain boundary segregation, Vacancy condensation, Crack propagation and fracture

FIZ/1/026 Current topics of materials science
1. Fundamentals of plastic deformation: Geometrical considerations, Schmid factor, Taylor factor, single and multiple slip. Temperature and strain rate dependence. Specific properties of fcc, bcc and hcp metals. Effect of grain size.
2. Work hardening: Mechanisms, influence of dislocations and other obstacles. Taylor equation. Influence of boundary surfaces, Hall-Petch equation. Work hardening stages, Mecking plot.
3. High temperature deformation: Fundamentals and sections of creep. Empirical relation between the temperature and stress dependence of the rate of deformation. The mechanisms of creep: dislocation mechanism, activation volume, diffusional mechanisms, Nabarro-Herring and Cobble creep, and their temperature and stress dependence.
4. Power-Law-Creep, the PLC effect, solute-drag and their temperature and stress dependence. Concomitant dislocation and diffusional mechanisms, parallel and serial switching, independent and sequential creep mechanisms. Dislocation-climb and glide mechanisms. The Hazzledine-Weertman model of dislocation-climb and glide. Deformation maps.
5. Internal stresses in heterogeneous systems. Pattern formation. The correlation between the internal stress and the strain
6. Temperature anomaly in the Ni3Al ordered intermetallic alloy system: Stacking faults in the LI2 structure. The definition of γ surfaces. Sections of γ surface of the ordered Ni3Al intermetallic alloy system along QRSTQ line (as in the MTA doctoral thesis of Géza Tichy) and along the cubic 001 direction. The description and operation of the Kaer-Wilsdorf lock.
7. Ni base γ/γ' superalloys: The structure and morphology. Rafting. Deformation mechanisms, internal stresses, creep resistance.
8. Fatigue: Woehler's diagram, fatigue limit. Cyclic stress strain curve. Formation of patterns. Operation of PSB, role of internal stresses. Mechanism of surface coarsening and role in fracture. Pattern formation.

FIZ/1/031 Technology of materials (intensive course)
9. Historical remarks. Technology of materials in ancient and medieval times.
10. Technology of materials as a part of materials physics.
11. Overview of materials for structural and some functional applications.
12. Thermomechanical treatment of important structural materials (steels and light alloys). Types of thermal treatment (annealing, quenching etc.), types of mechanical treatment (casting, rolling, forging etc.), microstructure refinement (equal-channel-angular-extrusion, torsion under high pressure etc.)
13. Surface engineering, surface modification
14. Technology and basic properties of ceramic materials, high temperature superconductors
15. Technology of polymers. Notes on conducting polymers
16. Technology and basic properties of some special materials. Liquid crystals, quasicrystals, metallic glasses, fullerenes, carbon nanotubes & onions, whiskers, cellular materials
17. Technology of composite materials.

FIZ/1/036 Composite materials
The properties and technologies of composite materials. Fiber reinforcements –classification, technology and properties. Matrix materials. Processing methods. Boundaries in the composites – interactions, bonding types, boundary strength. Polymer and ceramic based composites. Carbon fiber reinforced composites. Metal matrix composites – production, micro- and nanomechanics, strength, cracking, creep, fatigue, design. Surface treatment. Applications.

FIZ/1/037 Amorphous alloys
General properties and characterization of bulk amorphous materials. Brief summary of investigation methods. Characterization of structure: short (SRO) and medium (MRO) range order. Free volume model. Miracle model. Glass transition (Tg), glass formation (GFA), viscosity. Production of bulk amorphous materials, role of cooling rate. TTT-curves. Role of composition, phase diagrams. Inoue criterions. Relaxation. Mechanical properties of bulk amorphous materials: tensile testing, torsion, cracking...etc. Deformation mechanisms. Plasticity below Tg. Role of deformation bands. Characterization of amorphous nanocomposites. The effect of heat treatment and severe deformation on the microstructure.

Experimental methods used in material chatacterization

FIZ/1/021 Transmission electron microscopy and electron diffraction
The method of electron microscopy. Nature of the information obtained by this method. The construction of an electron microscope, electromagnetic lenses. Lens aberrations, resolution. Imaging modes of electron microscopes. Scattering of electrons by atoms, atom groups, diffraction by amorphous materials. Diffraction by crystals, by polycrystalline materials and textures. Size and strain effects. Phase analysis. Ewald construction. Kikuchi patterns, convergent beam electron diffraction. Kinematic and dynamic theory of image formation. Imaging and contrast of crystal defects. High-resolution microscopy, contrast transfer functions. Electron holography.

FIZ/1/014 Analytical electron microscopy
The subject gives a very short (1 lesson) introduction to the operation modes of a transmission electron microscope (TEM). The main topics for analytical electron microscopy (AEM):

- Elastic and inelastic scattering of high energy electrons and their application in electron diffraction (SAED, NBD, CBED)
- Analytical methods in the TEM (EELS, EFTEM, EDS)
- Current trends in AEM and HRTEM

FIZ/1/038 Diffraction methods in Materials Science I.
Basic concepts of crystallography. The kinematical theory of diffraction. Production of X-rays. Interaction between X-ray photons and materials. X-ray detectors. Absorption of X-rays. Diffraction methods. Debye-Scherrer camera. Powder diffractometer. Evaluation of powder diffractograms. Phase identification using database. Indexing of cubic structures. Determination of lattice parameter. Single crystal diffraction. Laue-method. Zone-axis. Crystallite size broadening of X-ray line profiles. Bertaut-theorem. Determination of the volume-weighted and area-weighted mean column length from the peak profile. Effect of anisotropic crystallite shape on line profiles. Strain broadening of X-ray diffraction peaks. Mean-square strain. Strain

broadening caused by dislocations. Strain anisotropy. Evaluation methods of diffraction line profiles. Comparison between TEM and X-ray line profile analysis methods for studying the microstructure.

FIZ/1/039 Diffraction methods in Materials Science II.
1 Fundamentals of neutron diffraction and applications.

2 Fundamentals of dynamic scattering and applications.

Advanced courses on solid state theory

FIZ/1/022 Solid state theory I
Movement of atoms, atomic interpretation of pressure, temperature and chemical potential, molecular dynamics, Monte Carlo method. Vibrations in solids, mode localization, non-harmonic oscillations. Bonds of metals, transition metals and semiconductors. Semiconductors and semiconductor equipment, operation of junction transistors.

FIZ/1/023 Solid state theory II
Nonperiodic systems. Amorphous materials and quasi-crystals. Electrons in nonperiodic space. Doped crystal, coherent potential theory. Ziman model of conductivity. Optical phenomena, Lyddane-Sachs-Teller relation.

FIZ/1/029 Solid state research I.
Review of several current research topics in solid state physics. Introduction to important experimental methods. Relation between crystal and electron structure and electric and magnetic properties.

FIZ/1/030 Solid state research II.
Localization-delocalization: Free volume model of glass transition, metal non-metal transition, percolation. Magnetism: Producion of magnetic field, magnetic measurements, neutron diffraction, magnetic structures, magnetic anisotropy, permanent magnets, soft magnetic materials, magnetic thin layers.

FIZ/1/041 Quantum bits in solids
Quantum information processing is expected to improve performing certain tasks in computation, communication, cryptography and metrology. The basic unit of quantum information is the quantum bit, which can be realized, for example, by the spin of a single electron. In these lectures, we first review the basic concepts of quantum information theory and a few important quantum algorithms (Deutsch, Grover, Shor). Then, we outline the theory of the fundamental physical mechanisms allowing for the initialization, control and readout of electron-spin-based quantum bits in solids, as well as the mechanisms leading to the loss of information encoded in these quantum bits. These mechanisms are associated to hyperfine, spin-orbit and electron-phonon interactions; the lectures will provide an introduction to these. If time permits, the basics of quantum bits based on superconducting circuit elements will also be covered. A goal of the lecture series is to provide an introduction to the physics of solid-state quantum bits, helping students to start a research activity in this field.

FIZ/1/042 Topological insulators I
An important finding of the previous decade is that even the (non-interacting) band theory of electrons in solids can provide fundamental novelties. Topological insulators are crystalline band-insulator materials accommodating conducting – occasionally perfectly conducting – surface states. In this lecture series we use simple models to introduce the topological invariants that are important in band theory, we provide theoretical tools to calculate those, and show how topology protects the surface states from certain perturbations. We provide insight into the general theory of topological insulators, and review a few related experimental arrangements and results.

FIZ/1/043 Topological insulators II
In a mean-field description, superconductors appear as band insulators for quasiparticles. This allows us to extend topological band theory to superconductors. The low energy, topologically protected bound states (edge states) become Majorana fermions (Majorana modes) with novel physical properties, which have recently attrected a lot of attention. We discuss the theoretical and experimental status of these states, and the foundations of their use for quantum information processing. The understanding of topological superconductors completes topological band theory. With the use of dimensional reduction we extend the bulk-boundary correspondence to describe the low energy physics (edge states) on defects of arbitrary dimension in bulk materials of arbitrary dimensions. In the remaining time we review other topics related to topological insulators.

FIZ/1/045 Low temperature plasma physics
The vast majority of the known matter in the Universe is in plasma state, characterized by the presence of free charged particles. Artificial plasmas play a distinct role in laboratories and in high-tech industry (e.g. in etching of surfaces, deposition of thin layers in integrated circuit and solar cell manufacturing, as well as in the creation of biocompatible surfaces). The course discusses the main parameters and characteristics of low-temperature (non-thermal) plasmas, the motion and the collision processes of charged particles. The methods of particle transport theory - solution of the Boltzmann equation and the Monte Carlo simulation approach - are presented. The physics of direct-current and radio-frequency plasma discharges and their description by a variety of numerical methods (fluid models, hybrid models and kinetic particle simulations) are discussed. The main methods of plasma diagnostics (optical spectroscopy and electric probes) are introduced. The physics of complex (dusty) plasmas and their description via molecular dynamics simulations (allowing access to structural and transport properties, as well as to the identification of collective excitations) are also covered.

FIZ/3/008 Pattern formation in complex systems
Introduction, definitions: spatial and/or temporal patterns in systems far from equilibrium; homogeneous, ordered (periodic) and chaotic states. Theoretical description: methods, dissipative dynamics, stability and bifurcations, linear stability analysis and nonlinear basic states. model equations. Nonlinear behavior in classical mechanics. Non-linear behavior in chemistry (Bjelousov-Zhabotinsky and Turing instabilities) Shear induced (flow) instabilities: Taylor-Couette, Rayleigh, Rayleigh-Taylor, Kelvin-Helmholtz, Benard-Marangoni instabilities. Thermally driven convection: Rayleigh-Benard instability. Role of anisotropy; thermal convection in liquid crystals. Electroconvection. Interfacial patterns: viscous fingering, linear stability analysis. Non-equilibrium solidification: dynamics of a solid-liquid interface. Non-linear optics. Computer simulation methods: DLA, phase-field model. Experimental techniques: shadow graph, image processing.

FIZ/3/013 Quantum chaos in mesoscopic systems

Billiards, Random matrix theory: symmetries, universal classes, Gaussian distribution, mixture distribution of eigenvalues, determine density of states with Coulomb gas method and Green function, nearest-neighbor distribution, Scars: theory and experiments, Random matrix theory applied to quantum transport: basics of experiments, scattering and transferring matrices: basic properties, low localization conductivity fluctuation.

FIZ/3/015 Carbon Nanostructures

Discovery of C60, historical survey, isolated cage like molecules.
Properties of C60 in gas- liquid- and solid phases.
Doped fullerenes, fullerites.
Fullerene polymers.
Carbon nanotubes: geometrical, vibrational and electronic properties.
Applications.

FIZ/3/016 Macromolecules

Flexible chain polymers: polymerization, polycondensation, distribution functions of polymers, basics of conformation analysis, local and global conformations, effect of cooperativity, statistical description of ideal polymers, the theta state, rubber flexibility. Conjugated carbon-chained polymers: conjugated constructs, linear chain – one dimension instabilities, effect of doping, insulator-metal transitions, solitons, polarons, bipolarons. Biological polymers: spatial structure of cellulose, analysis of protein structures with energetic calculations and statistical methods, theoretical analysis of trans-membrane proteins, spatial structure of DNA and its flexibility.

FIZ/3/022 Mesoscopic superconductors

In this course we give a review of the present status of the mesoscopic superconductivity.
Bogoliubov - de Gennes equation. Andreev reflection, proximity effect. Currents in superconductors. Scattering at normal-superconducting interface. Conductance of normal-superconducting hybrid systems. Superconducting-normal-superconducting systems: mesoscopic Josephson junctions. Gauge transformation of the Bogoliubov - de Gennes equation. Excitation spectrum for Andreev billiards.
Literature:
P. G. de Gennes: Superconductivity of Metals and Alloys (Benjamin, New York, 1996)
F. Andreev, Zh. Eksp. Teor. Fiz. 46, 1823 (1964), [Sov. Phys. JETP, 19, 1228 (1964)]
A. Abrikosov: Fundamental of the Theory of Metals, (Elsevier Science Publishers, Amsterdam, The Netherlands, 1988)
M. Tinkham: Introduction to Superconductivity, (McGraw-Hill, Inc., New York, 1996)
J. B. Ketterson and S. N. Song: Superconductivity, (Cambridge University Press, Cambridge, 1999)
C. J. Lambert and R. Raimondi, J. Phys. Condens. Matter 10, 901 (1998)
C. W. J. Beenakker, in Mesoscopic Physics, Les Houches Summer School, edited by E. Akkermans, G. Montambaux, J. L. Pichard, and J. Zinn-Justin (Elsevier Science B. V., Amsterdam, 1995); C. W. J. Beenakker, Review of Modern Physics 69, 731 (1997)
M. Brack and R. K. Bhaduri: Semiclassical Physics, (Addison-Wesley Pub. Co., Inc., Amsterdam, 1997)

FIZ/3/023 Physics of mesoscopic systems II.

In this course we give a review about the most relevant experiments and theories related to mesoscopic systems. The course is based on the course of Mesosopic Systems I.
Integer quantum Hall effect. Fractional quantum Hall effect. Quantum point contact. Coulomb blockade. Persistent current. Quantum dots, artificial atoms. Antidot lattice, classical and quantum chaos. Lateral magnetic super lattice (magnetically modulated mesoscopic systems). Photonic crystals. Shot noise. Spintronics.
Literature:
Supriyo Datta: Electronic Transport in Mesoscopic Systems (Cambridge Studies in Semiconductor Physics and Microelectronic Engineering) (Paperback)

C. W. J. Beenakker and H. van Houten in Quantum Transport in Semiconductor Nanostructures, Solid State Physics, Vol. 44, pp. 1-228, edited by H. Ehrenreich and D. Turnbull, (Academic Press, Inc., Boston, 1991)
Y. Imry: Introduction to Mesoscopic Physics, (Oxford University Press, Oxford, England, 1997)
D. K. Ferry and S. M. Goodnick: Transport in Nanostructures, (Cambridge University Press, Cambridge, 1997)
T. Heinzel: Mesoscopic Electronics in Solid State Nanostructures,(Wiley-VCH GmbH & Co. KGaA, Weinheim, 2003)
H-J. Stöckmann: Quantum Chaos, An Introduction,(Cambridge University Press, Cambridge, 2000)
C. W. J. Beenakker and C. Schönenberg: Quantum Shot Noise, Pysics Today May 2003, and References therein
D. Weiss, G. Lütjering, and K. Richter: Chaotic Electron motion in Macroscopic and Mesoscopic Antidot Lattices, Chaos, Soliton, & Fractals, Vol. 8, pp. 1337-1357
R. B. Laughlin: Noble Lecture: Fractional quantization, Review of Modern Physics, Vol. 71, 863 (1999) and References therein; H. L. Stromer: Noble Lecture: The fractional quantum Hall effect, Review of Modern Physics, Vol. 71, 875 (1999)
Spintronics and Quantum Computation, edited by D. D. Awschalom, D. Loss, and N. Samarth (Springer, Berlin, 2002) and References therein ; S. A. Wolf, D. D. Awschalom, R. A. Buhrman, J. M. Daughton, S. von Molnár, M. L. Roukes, A. Y. Chtchelkanova and D. M. Treger, Science Vol. 294, 1488 (2001)

FIZ/3/025 Trapped atomic systems

The goal of this course is to overview the modern experiments with trapped bosons and their theoretical background. The topics include:
Experiments with trapped ultracold boson gases. Bose condensation in trapped non-reacting model. The Gross-Pitevskii equation and its solution at zero temperature. Thomas-Fermi approximation for the condensatum. Density excitations, Bogoliubov equation. Quantum hydrodinamics for density wave modes. Atomic laser. Vortexes in quntum gases.

FIZ/3/028 Computer simulations in statistical physics

Introduction to simulation technics. Generation and testing of random numbers. Initial and boundary conditions. Data collection and reduction, finite size scaling. Geometrical problems, percolation, cluster statistics, polimer models. Monte-Carlo (MC) method in hamiltonian systems. Priority sampling. MC in canonical and other ensembles. Ising model. Special MC technics. Slowing down problems. Multispin coding. cluster-algorithms. Histogram technic. MC renormalization group. Optimization. Simulated heat treatment. Genetical algorithms. Molecule dynamics (MD). Algorithms, time stepping and event-triggered methods. Thermostat. Non-equilibrium MD. Growth models. Physical meaning of models defined by algorithm. Numerical solution of stochastic differential equations. Measuring of fractal dimension.
Cellular automata. Grading. Hydrodinamical cellular automatons. Self organizing critical systems. Game theory models.

FIZ/3/032 Phase transitions

Basic concepts and facts. A survey of examples. Mean-field approximation. Ising-model. Heisenberg-model, Mermin-Wagner theorem. Other models. Critical exponents: measurements, classical theory, high temperature series. The static scaling hypothesis and consequences. Renormalization group transformation. Fixed point, scaling, universality. Construction of the transformation in real space and in wavenumber space. A survey of results. Dynamical critical phenomena: conventional theory, dynamical scaling hypothesis, examples.

Recommended texts: L.D. Landau, E.M. Lifsic: Elméleti fizika V. (Tankönyv-kiadó, Budapest), E.H. Stanley: Introduction to Phase Transition and Critical Phenomena (Clarendon Press, Oxford 1971), S.K. Ma: Modern Theory of Critical Phenomena (Benjamin, London 1976).

FIZ/3/035 Many-body problem I.
Necessary background: Quantum mechanics, Statistical physics.
The course develops the quantum theory of many particle systems. The lectures of the first semester are devoted to normal systems using the temperature Green's function technique. The first part is devoted to the general formalism, while the second part concentrates on the electron gas. Occupation number representation: creation and annihilation operators. Definition of the temperature Green's function in grand canonical ensemble. Expression of equilibrium physical quantities in terms of them. Perturbation theory, Wick's theorem, Feynman diagrams. Self-energy and the Dyson equation. Hartree-Fock approximation.
Electron gas in homogeneous positive background. Calculation of the correlation energy. Spectral function, retarded Green's function, analytic properties, elementary excitations. Density propagator and its spectral function: perturbation theory and analytic properties. Collective excitations in the electron gas (the plasmon). The problem of stability of normal systems.
Literature:
E.M. Lifsic and L.P. Pitaevskii: Statistical Physics, Part 2 : Volume 9 (Pergamon, 1980)
A.L. Fetter and J.D. Walecka: Quantum Theory of Many-Particle Systems (McGraw-Hill, 1971)
P. Szépfalusy and G. Szirmai: Véges hõmérsékleti soktestprobléma (lecture notes available in Hungarian under http://www.complex.elte.hu/~szirmai/SP.pdf).

FIZ/3/040 Mesoscopic Systems I.
In this introductory course we summarize the basic physics of mesoscopic systems.
•Two-dimensional electron gas - nanoscale wires and quantum dots
•Electronic transport - Landauer approach
•Scattering matrix and transfer matrix method
•Green's function method (Fisher-Lee relation)
•Resonant tunneling
•Aharonov-Bohm effect
•Weak localizations
•Universal conductance fluctuations
Literature:
S. Datta: Electronic Transport in Mesoscopic Systems, (Cambridge University Press, Cambridge, 1995) C. W. J. Beenakker and H. van Houten in Quantum Transport in Semiconductor Nanostructures, Solid State Physics, Vol. 44, pp. 1-228, edited by H. Ehrenreich and D. Turnbull, (Academic Press, Inc., Boston, 1991)
Y. Imry: Introduction to Mesoscopic Physics, (Oxford University Press, Oxford, England, 1997)
D. K. Ferry and S. M. Goodnick: Transport in Nanostructures, (Cambridge University Press, Cambridge, 1997)
T. Heinzel: Mesoscopic Electronics in Solid State Nanostructures (Wiley-VCH GmbH & Co. KGaA, Weinheim, 2003)
H-J. Stöckmann: Quantum Chaos, An Introduction (Cambridge University Press, Cambridge, 2000)

FIZ/3/041 Trapped atomic systems II.
In this special course we continue the topics started in Trapped Atomic Gases I. The main interest is put on the current experiments performed in ultracold trapped gases. During the course theoretical issues of a few selected experiments are reviewed. Necessary backgrounds: Quantum Mechanics and Statistical Physics. Background on many body physics is beneficial.
•Field theoretical descriptions of weakly interacting particles in external trapping potential.

•A simple finite temperature approximation for the collective excitations: The Popov approximation for bosons.

•Experiments with rotating condensates with vortices.

•Thomas-Fermi approximation for a single vortex. Excitations of a stable single vortex ground state using the hydrodynamical approach. Sum-rule approach.

•Experiments with trapped fermions, observations of different phenomena in the BEC-BCS transition.

•The mean-field description of the BEC-BCS transition: the Leggett model.

Literature:

•Bose-Einstein Condensation in Atomic Gases, Editors: M. Inguscio, S. Stringari and C. E. Wieman, (IOS Press, Amsterdam, 1999) ISBN: 0-9673355-5-8

•F. Dalfovo, S. Giorgini, L. Pitaevskii and S. Stringari: Theory of Bose-Einstein condensation in trapped gases, Rev. Mod. Phys. 71, 463-512 (1999).

•Qijin Chen, Jelena Stajic, Shina Tan, Kathryn Levin: BCS-BEC Crossover: From High Temperature Superconductors to Ultracold Superfluids, Physics Reports 412, 1-88 (2005).

FIZ/3/042 Cooling and trapping of neutral atoms

We will introduce the basics of laser spectroscopy (spontanious emission, Rabi frequence, Bloch equations, quantum noise). We will discuss the effect of radiation pressure on center of mass motion of atoms in semiclassical approximation. We will derive the radiation pressure, gradient force, we will calculate the velocity dependent friction force acting on an atom. We will incorporate the diffusion by quantum noise in a Langevin equation. We will review the notable laser cooling (Doppler cooling, polarization gradient cooling, sideband cooling) and trapping (dipole trap, optical grid, magneto-optical trap) methods.

FIZ/3/051 Fundamentals of the Physics of Solids II

In this lecture we discuss some consequences of the electron-electron interaction in metals.
Main topics: Cohesive energy of the electron systems, Hartree-Fock approximation, exchange potential, correlation energy, Wigner crystal. Electronic response to external perturbations, dielectric function, RPA approximations, screening, Friedel oscillations, Kubo formula. Excitation in the interacting electron gas, quasiparticles and collective excitations, excitons.Landau Fermi liquid theory. Electronic phases with broken symmetry, spin-density waves, charge-density waves, superconducting state. Strongly correlated systems. The Hubbard model, magnetic order, ferro- and antiferromagnetism, metal-insulator transition.

FIZ/3/053 Theory of quantum phenomena

Density matrix, Wigner function, path integral etc. Entanglement, decoherence, master equations, quantum Langevin equations. The zoo of collapse theories. Aharonov-Bohm effect and Berry phases. The strange dynamics of tunneling. A short introduction to quantum information theory.

FIZ/3/054 Universality classes in non-equilibrium systems

Introduction to the dynamic scaling and classifying non-equilibrium universality classes

1. Introduction, dynamic scaling, critical exponents, field-theory formalism, renormalisation, topological phase diagrams, physical aging, scale invariance, transition to chaotic state
2. Dynamic expansion of basic critical statistical systems, domain growing, unsettled states.
3. Non-equilibrium universalities in settled fluctuating systems, systems driven by currents and fields
4. Basic non-equilibrium universality classes in absorbing transitions
5. Dynamic scaling in first order transitions
6. Non-equilibrium universalities in multi component systems, topological effects in low dimensions
7. Non-equilibrium surface-growth classes.

FIZ/3/060 Quantum information theory

The quantum information has become an important field of theorethical physics, mathematics, information technology and it is an ever present driving force for quantumtechnological developments. Present lectures are focused on theorethical physical aspects, not the mathematical, IT or engineering viewpoints. The course starts with the summery of theorethical basics of classical and quantum physics, preparing for some of the topics of quantuminformation theory (e.g. private key generation, teleportation, quantum entropies, quantum computer). Lectures notes are awailable in English: Springer Lecture Notes in Physics 713 (2007).

FIZ/3/061 Quantum information with quantum optics
Quantum optical description of light, modes.Quantum optics of one mode: Fock basis, step operators, coherent states, thermal state, squeezed vacuum in 1 and 2 modes. Beam splitter, passive, linear N ports. The concept of the qubit, 1 qubit operations, CNOT. Entanglement, quantum dense coding, teleportation, no-cloning theorem. Non-classical sources, photon detectors, homodyne detection. The principle of the non-linear and the linear optics quantum computer. Quantum walk and its optical realization, search algorithm via quantum walks. The principles of quantum cryptography and a realization with photons.

FIZ/3/062 Superconductivity
In this lecture we discuss the different phenomenological descriptions and the microscopic theory of the superconductivity. Main topics: Ginzburg-Landau theory, the order parameter, G-L equations, type I and type II superconductors, vortices, critical fields. The Bogoljubov-deGennes equations, mean field approximation, gauge symmetry breaking, Josephson effect. BCS theory of superconductors,pair formation, BCS Hamiltonian and the BCS Ground state, excited states of the superconductors. Strong coupling theory of the superconductivity, Eliashberg equations, retardation effects, tunneling, Andreev scattering. Overview of high Tc superconductors

FIZ/3/065 Synchrotron radiation and applications
The course presents the basics of synchrotrons and free electron lasers (FEL), the main types and specificities of the produced radiation in the X-ray, extreme UV, and IR ranges, and also its applications - in particular for structural studies in biology, pharmacology, and material sciences; large devices producing neutron beams and their applications will also be reviewed. The following areas will be discussed: physical basics of the interaction between radiation and matter; X-ray absorption spectroscopy (EXAFS and XANES) - enzyme structure and function, X-ray and neutron diffraction - crystal structure of macromolecules (and their super-complexes), quasi-crystals; small angle diffraction (SAXS, SANS) - membrane structures, ultra structure if protein aggregates, liquid crystal structures; reflectometry - mono and multi-layers; elastic and inelastic neutron scattering - structural dynamics of membranes and macromolecules; X-ray microscopy and micro-spectroscopy; far UV circular dichroism and other optical-spectroscopic applications.

FIZ/3/066 Theories of open quantum systems

Classical phenomenas, methods
- Diffusion vs stochastic trajectory equations
- Brownian motion: Fokker-Planck vs Langevin equation
- Microscopic derivations: just conceptions
- Master vs Ito equation, Monte-Carlo method
- Monitoring of noisy systems

Quantum phenomenas, methods
- Depolariation master vs q-trajectory equation
- Spontaneous decay master vs q-trajectory equation
- Q-Brown movement master vs q-trajectory equation
- Q-optical and/or Q-dot master equation
- Microscopic derivations
- Lindblad master vs q-trajectories, MC method
- Monitoring a Q system

FIZ/3/068 Green's functions in nanophysics
The aim of the course is to introduce techniques based on Green's functions to investigate transport phenomena on the nanoscale. The methods are than applied to a wide range of systems from simple tight-binding models to density functional theory based realistic systems.

FIZ/3/073 Group theory in solid state research
Introduction: point groups, fundamental theorems on finite groups, representations, character tables. Optical spectroscopy: selection rules, direct product representations, factor group. Electronic transitions: crystal field theory, SO(3) and SU(2) groups, correlation diagrams, crystal double groups. Symmetry of crystals: space groups, International Tables of Crystallography. Electronic states in solids: representations of space groups, compatibility rules

FIZ/3/074 Introduction to superconductivity
Phenomenology of superconductors. Meissner effect, London equations,electrodynamics of superconductors. Bardeen-Cooper.Schriffer theory: ground state, thermodynamic and transport properties. Ginzburg-Landau theory: free energy, GL equations and their solution, Abrikosov vortices, magnetic properties of Type II superconductors. Josephson effect and its applications. High-temperature superconductivity.

FIZ/3/076 Entanglement in quantum many-body systems
In the last decade it became clear that entanglement plays a crucial role in understanding the low-temperature physics of quantum many-body systems. Entanglement carries essential information about the ground states of quantum systems and the study of entanglement properties has become an indispensable tool of modern many-body physics research. In particular, the characterization of universality behind quantum critical phenomena has become unprecedentedly simple with the help of entanglement. It also plays an essential role in understanding the efficiency of modern numerical techniques, such as density matrix renormalization group method. The aim of the course is to give an overview about the essential results of this particular field. We start by introducing the basic concepts (e.g. reduced density matrix, entanglement entropy) as well as the main methods used to determine them. Focus will be given on exactly solvable lattice systems, where many different tools are available to extract the main quantities of interest. Apart from the detailed study of analytical methods, we will give an outlook on the basics of the most important numerical techniques.

FIZ/3/079 Stochastic processes
The course is about the description ot the dynamics of phenomena containing random elements. The outline is as follows. 1. Historical introduction about the probabilistic aspects of statistical physics and of quantum mechanics. 2. Einstein’s ideas about the random dynamics of Brownian motion and the steps leading from the Chapman-Kolmogorov equation to the Fokker-Planck equation. 3. Langevin’s approach to the Brownian motion and elements of a stochastic differential equation. 4. Probabilistic dynamics in a space of discrete states and the general properties of the Master equation. 5. Stationary state, relaxation to equilibrium, detailed balance, and the conditions the transitions should satisfy. 6. Birth-death type problems and generator-function formalism. 7. Simulation problems (kinetic Ising models). 8. Master equation approach to growing networks. 9. Langevin equation of overdamped oscillator, condition of equilibrium. 10. Current and voltage fluctuations, calculation of time-correlations. 11. Phase transitions and field-theoretic problems: Langevin equation with Gaussian noise and with various conservation laws.

FIZ/3/080 Simulating complex systems
This course gives a hands-on experience to various complex systems. With their own choice of programming environment and tools students simulate various systems, make numerical experiments,

demonstrate theoretical results via simulations and investigate phenomena which cannot be handled analytically. The results of these mini-studies are written up in lab reports in similar format to scientific papers. The topics are: Erdos-Renyi graphs, small-world networks, scale-free networks, degree distribution, percolation threshold, spectrum of graphs, Wigner semi-circle law, robustness against attacks, clique finding algorithms. Chaotic maps, dynamical chaos, dimension of attractors. Cellular automata. Neural network simulation and application for machine learning tasks.

FIZ/3/081 Computational modeling

The goal of the course is to introduce the students some of the state of art physics simulation codes which are actively used in various fields of research. The topics are continuously updated to follow the latest trends and developments of computer simulations. The students first learn the background of the given topic, read the related scientific papers, install and boot up the programs. This usually involves the usage of several software libraries (LAPACK, FFTW) and learning basic techniques of distributed and parallel programming (MPI, GPU). Now the GADGET gravitational N-body code, the OpenFOAM hydrodynamics simulation framework and the HOOMD-blue molecular dynamics package are used. After learning the background and installing the programs the students simulate various physical systems and write detailed reports in the style of scientific papers.

Program II: Astronomy and Particle Physics

Head of the program: Dr. Sándor Katz

Course descriptions

(all optional classroom courses for 6 credits, cannot be repeated, credits to be obtained: 48)

Particle Physics

FIZ/2/001 Advanced field theory

Non Abelian gauge theories, Fadeev-Popov quantization, BRST symmetry, Quantum effective action, renormalized BRST and renormalized action, alternative gauge fixings, Gribov copies and Gribov problem, U(1) problem

FIZ/2/002 The standard model

The structure of the standard model, renormalization, deep inelastic scattering, Weinberg angle, electron positron annihilation, LEP physics, Higgs physics, experimental tests of the standard model

FIZ/2/003 Beyond the standard model

The shortcomings of the standard model, grand unification, supersymmetry, technicolor models

FIZ/2/004 Experimental methods of particle physics II

The course will provide an introduction to the methods of modern experimental particle physics: accelerators, particle beams, detectors and softwares for data acquisition and analysis. We will also discuss some important experiment. (The first part of this course is part of the Master's programme.)

FIZ/2/005 String Theory I

The classic string. Nambu action. Reparameterization invariance. Equations of motion. Covariant gauge. Equations of motion in covariant gauge. Solutions. Constraints. Hamilton formalism. Poisson algebra. The remaining symmetries of the covariant gauge. Full gauge fixing with lightcone gauge. The solutions and the degrees of freedom in lightcone gauge. Quantization in covariant gauge. The Virasoro algebra of the constraints. The critical dimension of the bosonic string. Spectrum, tachyon.

FIZ/2/006 Completely integrable models of classical field theory

General equation for weak dispersion and weak non-linearity. Korteweg-deVries (KdVE) equation. Other interesting equations. Non-linear Schrödinger equation as the sine-Gordon equation. Scattering theory of one dimensional Schrödinger theory. Scattering datas from a given potential. Reconstruction of the potential. Inverse scattering. Lax pairs of the KdVE equation. Determining the time-dependence of the scattering datas of the potential solving the KdVE equation. Inverse scattering solution for the KdVE. Multi-soliton solutions. The KdVE as a Hamiltonian system. Scattering datas as the new dynamical variables. Infinite number of conserved quantities. Discrete systems: Toda and Langmuir lattices. Inverse scattering method for discrete systems. Generalization of the inverse scattering method for non-linear Schrödinger and sine-Gordon equations. Soliton, multi-soliton solutions, soliton-antisoliton scattering and bound states (breathing modes) of the sine-Gordon equation.

FIZ/2/007 Lattice field theory I.

Lattice regularization, renormalization group and continuum limit, scalar fields on the lattice, non Abelian gauge fields on the lattice, fermions on the lattice, chiral symmetry on the lattice, applications: finite temperature QCD, spectroscopy, electroweak phase transition

FIZ/2/008 Solitons and instantons I.
The structure of the space of finite energy configurations, the sine-Gordon and kink models, the general condition of integrability, Derrick's theorem, O(3) sigma model, monopole solutions of spontaneously broken gauge theories in d+1 dimensions, Bogomolny equation, BPS limit, the Yang-Mills instanton solutions

FIZ/2/009 Solitons and instantons II.
The principle of soliton quantization, kink mass and its renormalization, axiomatic framework, collective coordinates and their quantization, dilute instanton gas approximation, vacuum tunneling in 1+1 dimensional Abelian Higgs model

FIZ/2/010 Exact S matrices
Conservation laws and factorization, Yang-Baxter equation, general properties of two-particle S matrix (poles and bound states), bootstrap equations, ATTEs and their S matrices, the O(2) symmetric S matrix and the sine-Gordon model.

FIZ/2/011 Extra dimensional field theories
The standard model and its limits, renormalization. Hierarchy problem (HP). General discussion of the extra dimensions. Flat extra dimensional models. Curved extra dimensions. Phenomenology of the curved extra dimensions. Extra dimensional models without Higgs.

FIZ/2/012 Experimental heavy ion and particle physics
The course will review the results of CERN SPS, LEP, LHC and BNL AGS and RHIC accelerator facilities and the main goals of their experiments. We will discuss the operating principles of the most important detectors, namely Zero Degree Calorimeters (ZDC), Beam-to-Beam Counters (BBC), Forward calorimeters, Drift chambers (DC), Pad chambers (PC), Time of Flight Spectrometers (TOF), Electromagnetic calorimeters (PbSc, PbGl), Muon trackers, Muon identification detectors, Cherenkov detectors, Multiplicity-Vertex detectors, then discuss Data Aquisition Systems (DAQ), Triggers (Level-1, Level-2), online calibration, global track reconstruction and particle identification.

FIZ/2/013 Big bang in the laboratory – high energy heavy ion physics
Review of the most important experimental results of high energy heavy ion physics (CERN SPS, RHIC, LHC). Introduction to the main theoretical methods (Monte-Carlo simulations, analytical and numerical hydrodynamical solutions). Exact solutions of the fireball hydrodynamics in the case of non-relativistic, dissipative or relativistic perfect fluids. Applying the results in the analysis of experimental data, the Buda-Lund model. The Friedmann equations and their heavy ion physics analogues, mathematical relationship between the Big and „Little” Bang.

FIZ/2/014 Correlations in high energy physics

The HBT effect, Quantum-statistical correlations: Bose-Einstein and Fermi-Dirac, Coherent and squeezed states and intensity correlations of thermal sources, Nucleus glory model, Higher order correlation functions and their information content, Correlations due to the Coulomb and strong interactions, Correlation in e+e-, p+p and A+B collisions, Hydrodynamical models for correlations, The RHIC HBT puzzle and its solution, Pion lasers, The restoration of the $U_A(1)$ symmetry and its correlation signals, Correlations of not identical particles, Imaging methods, Femtoscopy

FIZ/2/015 Inflationary cosmology

Einstein equations, Boltzmann equation for relativistic matter. Inflationary initial conditions, field theoretical models of inflation. The evolution of dark matter. The cosmic microwave backround.

FIZ/2/016 Finite temperature quantum field theory and astrophysical applications

Fintie temperature quantum fields in equilibrium, theoretical methods to describe phase transitions in quantum field theory, phase diagram of QCD, time development of quantum fields near equilibrium, introduction to the theory of inflational period of the Universe, formation of the hot Universe

FIZ/2/017 Discrete gauge symmetries

The course is an introduction to discrete symmetries. Besides the general discussion of gauge theories and the physical relevance of the topic, we discuss the permutation symmetries in detail, where we describe the effects of gauge enhancement.

FIZ/2/018 Conform field theories

Conform field theories in two dimensions, the connection between the vertex operator algebras and the modular categories, instead of complete description of more traditional subjects we review some actual research topics

FIZ/2/019 Field theories with boundaries

This course deals with the description of classical and quantum field theories with flat boundaries. After the general foundation we concretely study the Casimir effect and the low dimensional integrable models.

FIZ/2/020 Algebraic field theory I.

Quantum mechanics and quantum field theory, the role of the infinitely many degrees of freedom, Neuman theorem, superselection sectors, C* algebras, operator algebras, Neumann algebras, representations of the C* algebras, axioms of the observable algebras, vacuum and admissible representations, localizable and transportable representations, Doplicher Haag Roberts sectors

FIZ/2/021 Introduction to general relativity I.

The course is devoted to the introduction of the modern theory and
applications of general relativity.
Introduction to differential geometry: differentiable manifolds, vector fields, tensor fields, covariant derivative, curvature, symmetries.

FIZ/2/022 Experimental methods of nuclear physics

The course is devoted to the introduction of modern experimental nuclear physics methods. Review of accelerators, beam sources, different kind of targets, gas detectors, scintillation detectors, semiconductor detectors and devices that can show the track of particles. Neutron detectors. Measurement of cross section and error estimation. Radiation protection, shielding. Life in a large scientific collaboration: organizational questions.

FIZ/2/023 Jet physics in hadron hadron and in heavy ion collisions

First the creation of high energy quarks and gluons in proton proton ollisions is considered, the collision and hadron creation processes are described by the parton model augmented QCD, the properties of the one particle hadron spectra are reviewed and the various distributions that characterize the creation of the various particles are compared, the basis of the mesaurement of two and three particle correlations is introduced and the main properties of these functions are discussed, in the second part it is discussed how the spectra and distributions measured in proton proton collisions may be modified in heavy ion collisions and investigate how the hypotetical formation of the collective quark gluon state may modify the previous properties, finally it summarized how the high energy jets (and the hadrons originating from them) diagnostize the density and other properties of the QGP state

FIZ/2/024 The phase diagram of strongly interacting matter

The strongly interacting states appearing in nuclear systems are reviewed together with their properties, their theoretical description and their experimental observation, starting from the nuclear matter composed of protons and neutrons through the meson and barion resonancies (together with their antiparticles) we arrive at the hadron matter, a review is given of the mean field models, after a brief review of high energy nucleon nucleon collisions the appearance of quark degrees of freedom and the formation of quark gluon plasma is investigated, the simplest descriptions of the quarkmatter and the quark gluon plasma are given and the measurable properties of the plasma state are described, the properties of the di-quark condensate (forming at high density and low temperature) are investigated, the possible appearance of the various phases in the interior of high mass neutron stars is discussed

FIZ/2/025 The physics of interstellar matter I

Propagation of electromagnetic radiation: flow equation, solving the flow equation; Einstein coefficients, solving the flow equation with Einstein coefficients, stimulated emission.
21-cm radiation of neutral hydrogen: formation, propagation, role in mapping out the Galaxy.
Molecules in interstellar matter: rotational, vibrational transitions, optical pumping, masers, CO, NH3, H2 molecules.

FIZ/2/036 Nucleosynthesis
The course is devoted to the synthesis of chemical elements in the Universe.

Syllabus: basics of nucleosynthesis using nuclear physics; the thermodynamics of the early Universe; Big Bang nucleosynthesis; hydrogen-burning stars; solar neutrinos; nucleosynthesis in large mass stars; synthesis of elements heavier than iron; further nucleosynthesis processes

FIZ/2/042 Functional integral in quantum field theory

Scalar field theory. Green-functions, generating functionals, Dyson-Schwinger equations. The Dyson-Wick canonical expansion. Solution as a functional integral, derivation of the Feynman rules. Connected and one particle irreducible generating functionals. Regularization and renormalization. Effective action and effective potential. Background field method. Semiclassical (WKB) approximation, calculation of the first quantum correction. Effective potential in one-loop approximation and its applications (spontaneous symmetry breaking, Coleman-Weinberg mechanism). Behaviour of perturbation theory in large orders. Instantons, quantum tunnelling and the decay of the false vacuum.

FIZ/2/043 Introduction to supersymmetry
Symmetry principles in physics, the Coleman-Mandula theorem, associative, Lie-, Clifford-, and Grassman-algebras, spinors and Grassmannian variables, Lie-superalgebras and their representations, linear and orthosymplectic superalgebras, "exceptional" superalgebras, supersymmetric extensions of Poincare-algebra, internal symmetries and central charges, the matter content of supermultipltes, physical consequences of supersymmetry

FIZ/2/045 The algebraic theory of the integrable models of classical fields theory

Basic concepts and the Liouville integrability. The Lax pair and the classical R-matrix. Spectral parameter dependent Lax pairs. Coadjoint orbits and Hamilton formalism. The R-matrix of the coadjoint orbits, The (matrix) Riemann-Hilbert problem. Integrable field theories and the monodromy matrix, ZS-construction in fields theories, the Poisson brackets of the monodromy matrix. The group of the dressing transformations. Soliton solutions.

FIZ/2/048 Higgs boson physics

Summary of the standard model; the Higgs sector in the standard model (mass, couplings); lower and upper bound for the theoretical Higgs mass; creation of the Higgs; decay of the Higgs; experimental research of the Higgs

FIZ/2/049 Experimental high energy physics: data analysis

- How to design large, complex detectors?
- How to measure relative and absolute luminosity?
- How to measure particle distributions?
- How to measure centrality?
- How to detect neutral pions, charged particles?
- How to measure identified-particle spectra?
- How to detect photons, electrons, electron pairs, muons, muon pairs and J/psi particles?
- How to measure particle beams and their correlations?
- How to measure HBT correlations?
- How to measure the elliptic flow? How to determine the reaction plane?
- How to determine fragmentation functions?

FIZ/2/050 Perturbative conformal field theory

After briefly reviewing the two dimensional conformal field theories we study the perturbation theory of its relevant operators based on the following topics:

- Conformal field theories on two dimesion: symmetry, spectrum, correlation functions
- Classification of the perturbations: beta function
- Approximation methods: conformal perturbation theory, truncated conformal space approximation
- Integrable perturbations, conserved quantities
- Generalizations with boundaries and defects

FIZ/2/052 Algebraic field theory II.

Categories, functors and natural transformations, the equivalence of DHR representations and the category of DHR morphisms in case of Haag dual vacuum representations, C* categories, monodial categories, braid group, braided categories, product of DHR morphisms, statistical operator and its properties, the braided monodial C* category of DHR morphisms, the role of the space time dimension, rigid C* categories, quantum dimensions, charge conjugation, left inverse and statistical parameters

FIZ/2/053 String theory II.

Extension of the bosonic string with worldsheet fermions in covariant gauge. The supersymmetry of the extended action. Superspace description of the action. Heuristic introduction of the extended constraints. Boundary condition for the fermionic fields. Neveu-Schwartz and Ramond sectors. Quantization of the fermionic fields. Super Virasoro algebra. Spectrum. Origin of the spacetime fermions. Critical dimension. Superstring in lightcone gauge. Lorentz invariance. Locally supersymmetric action. Derivation of the constraints. GSO projection. Spacetime supersymmetry. Type I superstring. Closed superstring theories and its spectrum. Type IIA and IIB and heterotic superstring theories. The problem of the extra dimensions. Consistency of the superstring theories, anomaly cancellation.

FIZ/2/054 String Theory III.

Path integral description of the string and the superstring theories. Vertex operators, string perturbation theory. Low energy limit. Supergravity theories. Missing anomaly.

FIZ/2/055 Lattice field theory II.

Non Abelian gauge fields on the lattice, fermions on the lattice, realizing chiral symmetry on the lattice

FIZ/2/056 Lattice field theory III.

Application: Finite temperature QCD, spectroscopy, electroweak phase transition.

FIZ/2/057 Introduction to general relativity II

Derivation of the Einstein equations from variational principles. Black holes. Cosmological models. Gravitational radiation.

FIZ/2/077 Completely integrable multiparticle systems

By means of the coordinate space Bethe Ansatz (BA) the solution of a large class of one dimensional (1D) many body systems can be reduced to solving a system of coupled algebraic equations, the so called Bethe Ansatz equations. Since the method can not be defined system independently in an abstract way, we try to demonstrate through the examples of several systems those generalyzable steps which are considered the elements of the coordinate space Bethe Ansatz. We present the solution strategy of the Bethe Ansatz equations and deal with the finite temperature description of these systems. In particular we focus on:

- The derivation of the BA equations for the 1D Heisenberg chain and 1D δ Bose-gas
- The nested Bethe Ansatz for diagonalyzing systems of particles with internal degrees of freedom (like the 1D δ-gas of spin 1/2 Fermions or the Hubbard chain)
- The method to solve the BA equations demonstrated on the case of the isotropic Heisenberg chain
- The structure of the solutions: the ”higher level BA equatios” describing the system of excitations
- BA systems in finite temperature (configuration entropy in BA systems): finite temperature analysis of the 1D Bose gas

FIZ/2/078 The algebraic Bethe Ansatz and its applications

The original formulation of Bethe Ansatz was applied to a one-dimensional (1D) many-particle model and has made assumptions for the wave function of the system. Today, Bethe Ansatz can be viewed in a wider context. It is a method for solving integrable (thus exactly solvable) 2D statistical and 1D quantum many-body models with a special algebraic structure (Yang-Baxter algebras). The present course is an introduction to the algebraic discussion of the appropriate integrable models. Our goal is to introduce the fundamental concepts and relations which allow to reduce the problem of integrating these models to solving algebraic equations. The main chapters of our discussion are the following:

- the structure of 2D vertex models (vertex operators, monodromy matrix, transfer matrix)
- 6-vertex model
- integrability of 2D vertex models, Yang-Baxter algebra
- solution of the Yang-Baxter equations for the 6-vertex model
- the connection between 2D statistical and 1D quantum models
- the diagonalization of transfer matrix: the algebraic Bethe Ansatz
- examples of the appearance of the Yang-Baxter structure in 1D quantum systems

FIZ/2/079 Quantum information theory

In the past 15 years the Quantum information theory has become an important area in theoretical physics, mathematics and informatics, and it continuously helps the developments of quantum technology. The specialty of these lectures is the theoretical physical approach, not the mathematical, informatical or the engineering one. The course begins with the summary of the theoretical basics of classical and quantum physics, preparing some chapters of the quantum information theory (for example quantum key distribution, teleportation, quantum entropies, quantum computers). The lectures have been published in English: Springer Lecture Notes in Physics 713 (2007).

FIZ/2/081 Weak interaction

Historic review, conserved quantities and selection rules, muon decay, strangness conserving semileptonic processes, beta decay, conserved vector current, axial form factors, semileptonic decay of kaons and hyperons, non leptonic kaon decay and the neutral K meson, GIM mechanism, tau lepton, b quark and the flavour families, Kobayashi-Maskawa matrix, the limits of current-current theory, spontaneous symmetry breaking and the Higgs mechanism, the bosonic and fermionic sector of the Salam-Weinberg model, the basis of grand unification

FIZ/2/083 Quantum chromodynamics

The formation of QCD, Lagrangian, quantization, renormalization, the equations of the renormalization group, asymptotic freedom and the asymptotic behaviour of Green's functions, electron positron annihilation, jet physics, deep inelastic scattering, the QCD description of hard processes

FIZ/2/084 Integrable field theories

Integrable classical models (multiparticle solutions, time delay, conserved charges, condition of integrability), Quantum integrable models (quantization starting from a conformal field theory, quantization based on a Lagrangian perturbation theory [S matrix and its relation to correlation functions, its analytis structure], bootstrap quantization [the properties of the integrable S matrix, Zamolodchikov-Fateev algebra, the bootstrap program], quantization based on lattice regularization [the solution of the inhomogeneous XXZ model], correlation functions and form factors), quantum integrable models in finite volumes (Bethe-Yang equations, Luscher corrections, TBA)

FIZ/2/086 Solitons and instantons III.

Historic review of Yang-Mills instantons and their role in quantum theory, their importance in SUSY Yang-Mills theories, ADHM construction on R^4, Nahm transformation on compact T^4, T^m and R^n spaces, the moduli space of instantons, Kahler and hyper-Kahler geometries and their use in describing instanton moduli spaces.

FIZ/2/088 Finite temperature and non-equilibrium quantum field theory

The path integral with initial conditions, real and imaginary time formalism; perturbation theory, propagators, counterterms, renormalization, causality and analicity, cutting rules; thermodynamics, free energy, phase transitions, linear response theory, state decay, Kubo formula, Wigner transformation, Boltzmann equations; classical field theoretic limit; renormalization group in real time formalism, Feynman-Vernon construction, noise, fluctuation-dissipation theorem, Tsallis distribution; IR divergences, summing, 2PI formalism, Schwinger-Dyson equations; O(N) model in finite temperature, phase diagram, gauge theory in finite temperature, HTL action action, Vlasov equations, Wong equation, phase diagram of QCD.

FIZ/2/090 Advanced renormalization I

The basics of QFT in the path integral formalism. Feynman diagrams and their calculation. Control flow. Arrays, strings and pointers. Functions – basics divergencies, regularization methods. Power counting. Fundamental concepts of renormalization, formalism with counterterms. Dimensional regularization. Renormalization at arbitrary order. BPHZ formalism. Renormalization without regulators. The locality of counterterms, Weinberg theorem. Renormalization of composite operators, operator mixing. Renormalization and symmetries I: global symmetries, Ward identities. Renormalization and symmetries II: renormalization of spontaneously broken theories.

FIZ/2/091 Advanced renormalization II

Dilatations. Breaking of scale invariance. The Callan-Symanzik renormalization group equation as the Ward identity of the anomalous scale invariance. Chiral anomaly. Renormalization group. Large mass expansion, decoupling theorem. Wilson's operator product expansion. Renormalization and symmetry III: local symmetries, renormalization of gauge theories. Renormalization beyond perturbation theory. Physical interpretation. Quantum field theory models as low-energy effective description.

FIZ/2/092 Quantumelectrodynamics

Canonical quantization, the theory of symmetries, space time symmetries, free scalar field theory, charge conjugation, free electorn positron field, electromagnetic field in Lorentz gauge, free charged vector field, interaction picture, S matrix, transition probabilities and cross sections, normal ordering, Wick algebra, Feynman rules in momentum space, explicite computation of some simple processes, the basis of functional integration, Feynman functional integral in quantum field theories, bases of non-Abelian gauge theories

FIZ/2/094 High energy heavy ion physics and the perfect quark fluid
The Big Bang and high energy heavy ion physics. Colliders and collider experiments. Detector types and observable quantities. Detailed structure and functions of a typical experimental facility. Discovery of jet quenching, the elliptic flow and the strongly interacting quark gluon plasma. Transition between hadronic and quark matter. Bose-Einstein correlations. Hydrodynamics in relativistic heavy ion collisions, the perfect quark fluid.

FIZ/2/104 Integrable methods in gauge/gravity duality I
Syllabus: -superconformal algebra - Green-Schwarz string as coset model -integrability of classical superstrings - light cone gauge - decompactification, perturbative S-matrix - symmetries, exact S-matrix

FIZ/2/109 Integrability methods in gauge/gravity duality

The exact AdS5XS5 S matrix, classification of bound states, asymptotic Bethe Ansatz, finite size corrections, thermodynamic Bethe Ansatz

FIZ/2/110 Statistical field theory

The lecture gives an introduction to application of relativistic quantum field theories in statistical physical system. After discussing the critical phenomena and scaling we turn to the field theoretical description. We discuss the conformal symmetry, the operator product algebra, the classification of operators and states, and the partition function and correlation functions. The systems close to the critical point can be described by relevant perturbation of conform field theories. In two dimensions an interesting class of these theories are integrable models, and in this case the exact computation of the scattering matrix and the matrix elements of operator is possible. We discuss the foundation of theory of finite size effects, and some results for non-integrable models. Though the knowledge of the basics of quantum field theory is not a precondition, but highly recommended (Canonical quantization of free fields, basics of functional integral formalism, Feynman rules).

FIZ/2/111 Introduction to Einstein's gravitation theory I.

The planned two semester lectures offer a well-established introduction to Einstein's gravitation theory also known in the everyday language as the general relativity. The first semester gives a modern introduction to the differential geometry, what is also usable in some other topics in theoretical physics. The titles of the main chapters are the following:
Topology, manifold, vectors;
Forms, tensors, metric;
Covariant derivative, Lie derivative;
Killing-fields, symmetries, curvature;
Geodetics, methods for calculation of the curvature;
Spacetime, special and general covariance, matter fields in spacetime;
Orientability, integration in curved manifolds.

FIZ/2/112 Introduction to Einstein's gravitation theory II.

In the second semester the most important and actively researched fields of Einstein's gravity theory will be presented. The titles of the main chapters are the following:
The Einstein equations, linearized gravity equations;
Gravity waves;
Homogeneous and isotropic cosmologies; Friedmann-Robertson-Walker spacetimes;
Spherically symmetric spacetimes, Schwarzschild solution;
The most important empirical evidences which confirm the validity of the theory;
Equilibrium of relativistic stars;
Final state of stars, gravitational collapse;
(Thermo)dynamics of black holes.

FIZ/2/113 Topics in the quantum world

1. Basics of quantum mechanics: Events, probabilities.
2. The edifications of the EPR experiment. The Pitowsky theorem and the problems with the interpretation of property. Issue of local hidden parameters. Non-communication theorem.
3. Consistent histories: The settings of the consistent probability interpretation of QM.
4. The double-slit interference experiment and the EPR in consistent history formalism. Bohr complementarity principle.
5. Description of macroscopic systems: collective variables, quasi-projections. Weyl's symbols. Classical dynamics.
6. Demonstration of the measurement problem in q-bit systems. Information theory approach.

8. Decoherence as the environment induced superselection.
9. Decoherence in the phase space (Caldeira-Leggett model)
10. The QM in respect of the decoherence, ‘derivation’ of the Born-rule.

FIZ/2/117 Selected chapters from experimental high energy physics
The course aims to familiarize the students — through the lectures of leading experts — with today's experimental particle and nuclear physics research, in particular those areas that are pursued at an outstanding level by researchers in Hungary. Selected topics include accelerator technology, modern particle detectors and large detector systems, reconstruction and identification of physics objects, statistical methods in data analysis, as well as a wide range physics research. The students will learn about the physics of the Higgs boson, the electroweak vector bosons and hadronic final states and get an introduction to the open questions in high energy physics, such as the search for New Physics beyond the Standard Model and the efforts to characterize quark-gluon plasma.

FIZ/2/118 High energy astrophysics

A survey of the hottest and most energetic objects in the Universe and their radiation. Topics include: techniques of X-ray and gamma-ray astronomy; observations of neutron stars (pulsars) and black holes; accretion disks and relativistic jets; supernovae, supernova remnants, gamma-ray bursts, quasars and active galactic nuclei; clusters of galaxies; cosmic rays, neutrinos and gravitational waves

Astronomy and Space Science

Methods of astronomy

FIZ/2/026 Astrostatistics I
Astronomical information is coming from multivariate observational data; The fundamental equation of stellar statistics is dependent on the probability density function of a sum of stochastic variables; The concept of the characteristic function, the central limit theorem, remarks on the law of large numbers; Statistical tests, simple test for the mean value, tests for distributions (KS test); Covariance and correlation, remarks on the two-dimensional Gaussian distribution, testing for stochastic independence, covariance and correlation matrix, partial correlation, multiple correlation, nonlinear dependence. The classification of multivariate methods. Principal component analysis, factor analysis, cluster analysis. Astronomical applications of multivariate methods.
Solar System and exoplanetary systems

FIZ/2/030 Selected chapters from hydrodynamics and magnetohydrodynamics I
Foundational equations. Fluids and plasmas in astrophysics. Ideal fluids. Viscous fluids. Gas dynamics. Turbulence and instabilities. The foundation of magnetohydrodynamics. Dynamo theory.

FIZ/2/031 Advanced informatics in astronomy I
Introduction to data analysis. Working with large databases. Direct access to online databases. Basics of statistical analysis. The equations of fluid dynamics, properties, typical problems. Main computational methods of fluid dynamics. Numerical calculation and programming of related astrophysical problems.

FIZ/2/032 Radio astronomy I
Historical overview, early discoveries. The methods of radio astronomy. Radio emission mechanisms. Radio telescopes and radio interferometry. Aperture synthesis, huge interferometer

systems (Westerbork, VLA, MERLIN). Very-long-baseline interferometry (VLBI). Space VLBI calibration and image reconstruction methods. Next-generation radio telescopes (ALMA, LOFAR, SKA). SETI: search for extraterrestial intelligence.

FIZ/2/034 Observational methods in astrophysics
Telescopes and detectors for ground-based astrophysical measurements. Optical, infrared, radio, UV, X-ray and gamma-ray astronomy using telescopes orbiting the Earth. Distance measurements in astronomy based on astrophysical methods and principles. State parameters of stars and their determination: spectral type, temperature, mass, radius, magnetic field, rotation. Photometric observations, photometric systems, extinction/reddening correction. Spectroscopic observations, spectrographs. The astrophysical information gained from line profiles. Radial velocity of astronomical objects, with an emphasis on exoplanets and Hubble's law.

FIZ/2/035 Radio spectroscopy in astronomy
Physical principles behind the radiation of media and bodies, measurement techniques. Utilizing radio spectroscopy data in astrophysics. Current and planned radio astronomy apparatus. Reduction of measurement data, software packages. Processing and analyzing reduced data.

FIZ/2/038 Astrophysical turbulence, dynamos and reconnection 1.
Introduction: what is turbulence? Turbulent transport and its importance in astrophysics.
Instabilities leading to turbulence. Shear instabilities, Orr-Sommerfeld equation, Rayleigh criterion. Types of shear flows. Instabilities of rotating flows: solar tachocline, accretion disks. Convective instability. Instabilities in diffuse matter and interstellar turbulence. MHD instabilities and turbulence. Models of reconnection, role of anomalous diffusivity. Tearing mode and impulsive bursty reconnection.
Mixing length models of turbulent transport. Mixing length theory of convection. alpha-model of accretion disks. Turbulent magnetic diffusion and its application. Sunspot decay. Role of mixing-length approach in reconnection.

FIZ/2/039 Space astronomy I
We present chapters from the history of space research in relation to astronomy. While doing so, we provide basic knowledge on the topic, from logistics to an overview of technical solutions. Based on this knowledge, students get acquainted with modern measurement techniques of astronomical projects and recent scientific results while solving problems, together and on their own. Problems include project planning, and the review and presentation of the literature.

FIZ/2/040 Infrared Astronomy I
We discuss metrology, data acquisition methods and data analysis in the lectures. In the tutorial class we review the recent literature, and we apply in practice the concepts learned in the lectures by processing and analyzing real measurement data.

FIZ/2/059 Astrostatistics II
Astronomical information is coming from multivariate observational data; The fundamental equation of stellar statistics is dependent on the probability density function of a sum of stochastic variables; The concept of the characteristic function, the central limit theorem, remarks on the law of large numbers; Statistical tests, simple test for the mean value, tests for distributions (KS test); Covariance and correlation, remarks on the two-dimensional Gaussian distribution, testing for stochastic independence, covariance and correlation matrix, partial correlation, multiple correlation, nonlinear dependence. The classification of multivariate methods. Principal component analysis, factor analysis, cluster analysis. Astronomical applications of multivariate methods.

FIZ/2/063 Selected chapters from hydrodynamics and magnetohydrodynamics II

Foundational equations. Fluids and plasmas in astrophysics. Ideal fluids. Viscous fluids. Gas dynamics. Turbulence and instabilities. The foundation of magnetohydrodynamics. Dynamo theory.

FIZ/2/064 Advanced informatics in astronomy II
Main computational methods of fluid dynamics. Numerical calculation and programming of related astrophysical problems.

FIZ/2/065 Radio astronomy II
Classification of astronomical radio sources. The radio emission of the Sun, planetary radio sources, radar observations. The center of the Galaxy. Radio sources in the Galaxy: supernova remnants, pulsars, stars, HI and HII regions, molecular clouds. Extragalactic radio sources. Active galactic nuclei. Cosmological applications. High frequency background radiation. The application of VLBI in astrometry and geodesy.

FIZ/2/067 Astrophysical turbulence, dynamos and reconnection II.
Theory of homogeneous turbulence. Correlation functions, Fourier space. Spectral models. Inertial range scaling, direct and inverse cascades. Kolmogorov, Iroshnikov-Kraichnan and Goldreich-Sridhar spectra. Processes in the dissipation range. Inhomognenous turbulence beyond mixing length theory. k-epsilon modelling, Reynolds stress approach. Sophisticated models of convection and interstellar turbulence.
Introduction to dynamo theory. Mathematical, technical, geo- and astrophysical dynamos. Antidynamo theorems. Turbulent dynamos, mean field theory. Classic dynamo equations, alpha-omega dynamos. Models of the solar, planetary and galactic dynamos. Large and small scale dynamos. The cosmological dynamo.

FIZ/2/068 Infrared Astronomy II
We discuss metrology, data acquisition methods and data analysis in the lectures. In the tutorial class we review the recent literature, and we apply in practice the concepts learned in the lectures by processing and analyzing real measurement data.

FIZ/2/072 Space astronomy II
Leaning on the syllabus of the first semester, students get acquainted with modern measurement techniques of astronomical projects and recent scientific results while solving problems, together and on their own.

FIZ/2/073 Linear and non-linear MHD waves
According to recent observations by space probes, plasma in space is dynamic, with waves and oscillations found in the solar atmosphere, and in almost all regions of interplanetary space. Their presence has significant implications regarding the dynamics of solar and space plasma, and their heating and stability. Using methods from seismology, the magnetic fields and the plasma were successfully analyzed based on the waves. The goal of the lectures is the mathematical description of linear and non-linear waves in structured space plasmas, and the application of this knowledge in investigating complex problems such as plasma heating/acceleration, and plasma and space diagnostics. We concentrate on these areas especially:
- Basic properties of solar and space plasmas, observing waves and oscillations in the solar atmosphere
- Magnetohydrodynamic (MHD) equations and wave solutions
- Linear MHD waves and oscillations in magnetic media
- Linear MHD waves and oscillations in inhomogeneous plasmas: Klein-Gordon equation, resonant coupling of waves, plasma heating
- Non-linear waves: shockwaves and solitons
- Applications for the theory of MHD waves and oscillations: the asteroseismology of the inside and atmosphere of the Sun

FIZ/2/075 Working with astronomical databases
Modern instruments have revolutionized various sciences, including astronomy. Telescopes and satellites generate such a large amount of data that handling it is impossible with traditional methods. Luckily, computational science and information technology provide us with numerous tools to solve this problem. We

can only utilize these tools well if we understand their mechanism of operation. The objective of the course is to give a detailed look into the world of databases, show the optimal usage of database management systems, and teach the language of database access (SQL).
- Role of databases in astronomy, large astronomical archives
- The technological basis of Virtual Observatories
- The structure of databases, operating principles
- Basics of the SQL language
- Overview of available systems, introduction to an actual database system
- Creating databases, managing user permissions
- Optimal data schemas
- Indexing, keys
- Transaction management
- Stored procedures, functions, integrating procedural codes
- The fine-tuning of databases

FIZ/2/089 Object-oriented C++ programming and applications in astronomy
C/C++ basics
The basic types, operators and expressions in C
Control flow
Arrays, strings and pointers
Functions – basics
Functions – in more detail
Further types and operators
Classes and objects
Classes – in more detail
Inheritance, virtual functions and polymorphism
I/O in C++
Exception handling, templates and other advanced topics

FIZ/2/107 N-body simulations in Astrophysics and Cosmology
Description of theoretical foundations of N-body simulations. Introduction of the public domain „Gadget" code. Introduction of required (and also publicly available) initial condition generators. Performing a simple simulation and visualization of results (in groups of two students).

Solar System and exoplanetary systems

FIZ/2/029 Perturbation methods in celestial mechanics I
The foundations of Hamiltonian mechanics. Nearly integrable Hamiltonian systems. Lie transform perturbation theory. Normal forms. KAM tori. KAM theorem. Single-resonance dynamics. Resonant action-angle variables. Numerical methods of detecting chaos. Lyapunov exponents, fast Lyapunov indicator, frequency analysis. Interactions between resonances. Nekhorosev's theorem. The secular dynamics of planets.

FIZ/2/062 Perturbation methods in celestial mechanics II
Secular dynamics of small astronomical bodies. Proper elements, secular resonances. Mean motion resonances. Resonance overlapping. Three-body resonances. Secular dynamics in mean motion resonances. Asteroid belt, Kuiper belt. Global dynamical structure of the belt of small bodies. Chaotic zones, chaotic diffusion and macroscopic instability.

FIZ/2/071 Physics of the solar atmosphere
Models of the solar atmosphere. 1D models: HSRA, VAL. 3D simulations and new chemical abundances.

Magnetic structuring of the solar atmosphere. Force-free fields, potential fields. Magnetic helicity, magnetic potential energy. Extremum theorems, Taylor conjecture, Aly-Sturrock conjecture. Numerical methods for the calculation of force-free fields. Helicity budget of the solar atmosphere. Origin of magnetic helicity.
Magnetoconvection, flux expulsion, intermittent fields. Convective collapse and other mechanisms of field amplification. Magnetic canopy vs. magnetic carpet. Small-scale dynamo and turbulent magnetic fields in the solar photosphere.
Physics of solar activity phenomena. Sunspot models. The problem of the penumbra. Faculae: hot wall vs. hot cloud model. Prominence equilibria: Kippenhahn-Schlüter model, Kuperus-Raadu model. Mechanisms for solar eruptions: flux cancellation, breakout, kink instability. Magnetic reconnection. Particle acceleration in flares. Thick target model.

FIZ/2/082 The physics of plasmas in the Solar System
Plasma physics processes in the Solar System are introduced based on the measurements of the Cassini mission near Saturn, tackling their theoretical foundations, similarities and differences.
I) The introductory lecture provides an overview of the Cassini mission and its measurements, devices and strategy.
II) The theory is summarized, including the kinetic description of plasma, the magnetohydrodynamic approximation and the study of plasmas using test particles.
III) The interaction between solar winds and Saturn, the concept of the surface of discontinuity, the magnetosphere of the planet, sources and absorbers, periodic phenomena.
IV) The magnetic sheet of Saturn and its plasma environment.
V) The moons of Saturn: Enceladus and Titan. The interaction of the moons and the magnetosphere.

FIZ/2/095 Physics of the heliosphere
Sun-Earth relationship, sunspot cycle, early observations. The theoretical model of the solar wind, properties of the solar wind. Physics of space plasmas, motion of charged particles, fluid description. The magnetic field of the heliosphere, the freezing of magnetic flux. Waves and turbulence, surfaces of discontinuity, shockwaves. Transient phenomena in the solar wind. The boundary of supersonic solar wind, properties of the outer heliosphere. Modulation of cosmic rays. Interaction of solar wind and astronomical bodies. Space weather.

FIZ/2/098 Small and microscopic astronomical objects in the Solar System
- The present composition of the Solar System:
Main-belt asteroids, near-Earth asteroids
The structure of the Kuiper belt, most interesting objects (dwarf planets)
The interplanetary dust disk
- Asteroids and interplanetary dust at different wavelengths
- Surface models for asteroids:
The standard thermal model, improved variants and alternatives
- Surface chemistry of Kuiper belt objects, the local "weather", volatile matter
- Internal structure of Kuiper belt objects
- Binary Kuiper belt objects: the Pluto-Charon system, moons of dwarf planets
- The Kuiper-Edgeworth debris disk:
How would the Solar System look from the outside?
Comparison with debris disks around other stars
- The formation and evolution of the interplanetary dust disk and the Kuiper belt
Kenyon and Bromley models
The migration of Neptune, the "Nice" model
"Late Heavy Bombardment"

FIZ/2/101 Modern methods in exoplanet research

The aim of the lecture is to introduce the most recent methods with which we can discover, measure, or just simply gather more information about planets outside the Solar System. Because of the common historical background, and the similarities between mathematical tools, we will also investigate at several points the physics of the Solar System and multiple star systems.

- Introduction: A bit of history. Discoveries in the Solar System: planets, moons, asteroids, Kuiper belt, binary systems. The beginnings of astrophysics: variable stars, eclipsing variables: Algol, transits and eclipses, fundamental parameters of stars, spectroscopy.

- What we are interested in: planets beyond the Solar System.

- First discoveries: pulsars, then precise radial velocity measurements and planets around main-sequence stars. Eclipsing systems, direct imaging, multiple systems, multiple eclipses, hierarchical systems, timing and time intervals, secular variations. What we still have not observed: Moonlike companions.

- Technical background: radio astronomy, optical spectroscopy, imaging and coronagraph techniques, near and far infrared observations.

- Mathematical tools and theoretical models: Kepler's laws, Newtonian dynamics, perturbations, numerical computations, motion of moons. Stellar evolution. Stability and chaos. Thermal radiation. Star formation and evolution.

- Kepler's laws. Orbital elements in two and three dimensions. The appropriate choice of orbital elements. Two-body problem vs. 1st one-body problem. Analytical approaches: translation functions and trigonometric functions, relationship of orbital elements and coordinates.

- The center of mass. Examples from the Solar System: Jupiter, Saturn, Earth-Moon, Pluto-Charon. Mass ratios and geometric ratios. The first planetary systems beyond the Solar System: planets around pulsars and main-sequence stars.

- Datasets of radial velocity measurements. Observable quantities: zero point, full and normalized amplitude, excentricity, orbital phases. Functional modeling and observational errors. Other required parameters that are only measurable through other means. The problem of orbital inclination. Observational strategies and efficient scheduling of measurements.

- Eclipsing systems. Background: detached eclipsing binary stars, double-lined spectroscopic binaries. Small-mass companions: center of mass, and a smaller set of determinable parameters. Orbital inclination. Connection to the radial velocity method. Selection effects and hot Jupiters: the first discoveries.

- The geometry of eclipses, secondary eclipses. Relationship between parameters of the system and observable quantities. The transit center, transit length, transit slope and transit depth. Start and end of transit, impact parameter, non-physical parameter ranges. Signal attenuation, blending. The atmosphere of the star: limb darkening and photometric bands. Background of secondary eclipses: detached eclipsing binaries. Relation of phases and eclipse lengths to the Laplace vector. Optical and near-infrared photometry of close systems: surface and atmosphere.

- Discoveries, and the characterization of unique systems. Scheduling strategies, signal-to-noise ratio, probability of false detections. Continuous observations. Reinforcements and astrophysical mistakes. Ground-based
surveys and discrete observation windows. Satellite projects: Corot, Kepler.
Projects based on continuous observation.

- Interactions. Radial velocity curve distortions: orbiting the same plane, orbital inclinations, mutual inclinations. Variability in eclipsing parameters. Lightcurve distortions, Lie series. Secular dynamics: general relativity, stellar flattening. The role of the impact parameter, critical values. Mutual eclipses and mutual orbital inclinations. Indirect detections and related constraints. Lower and upper boundaries.

- Interesting systems. Direct imaging and diffuse light. Systems similar to the Solar System. The neighborhood of planets. Zodiacal light, diffuse light, thermal radiation, infrared surplus. Debris disks and the Kuiper belt.

FIZ/2/102 On the edge of the Solar System

On the edge of the Solar System: the physics of astronomical objects in the Kuiper-Edgeworth belt. The current structure of the Solar System: Kuiper belt surveys, statistics, the structure of the Kuiper belt, most interesting objects (dwarf planets). Kuiper belt objects at different wavelengths: diffuse sunlight, thermal emission, millimeter wavelengths, spectral energy distribution. Surface models for asteroids: the standard thermal model, improved variants and alternatives. Surface chemistry of Kuiper belt objects, the local "weather". Internal structure of Kuiper belt objects. Binary Kuiper belt objects. The Pluto-Charon system. The Kuiper-Edgeworth debris disk: how would the edge of the Solar System look from the outside? Comparison with debris disks around other stars. The formation and evolution of the Kuiper belt: Kenyon and Bromley models. The migration of Neptune, "Late Heavy Bombardment".

FIZ/2/103 The formation of planets and planetary systems

According to the generally accepted theories, planet formation takes place in protoplanetary disks. A protoplanetary disk is formed around a star from a collapsing giant molecular cloud in the early stages of stellar evolution. For the formation of giant planets, there are two competing theories. According to the first, in a massive protoplanetary disk gravitational instabilities arise, leading to the the fragmentation of the gas disk. If fragmented parts can cool effectively, they could collapse due to their own gravity, since they can radiate away the released gravitational energy. The lack of an efficient cooling mechanism is one of the largest problems of the gravitational instability theory. Another issue is that the resulting fragments would lead to too massive planets, and the formation of Earth-like planets cannot be explained by this theory. According to the planetesimal hypothesis, the formation of planets starts during the coagulation of cosmic dust. In the beginning, dust is made up of sub-micrometer grains, which then become aggregates with radii around several meters due to coagulation. The size of these aggregates grows during small-speed random collisions, until a size of a few times 10 kilometers is reached. From that point on, the collisions and the stability of the resulting bodies are supported by their own gravity. During the collisions, in the region closer to the star Earth-like planets are formed, while outside the snow line planetary cores of 5-10 Earth masses form, which can accrete gas to grow into giant planets, as stated by the core accretion hypothesis. Following the escape of gaseous matter, the thus formed planetary system evolves dynamically, governed only by the gravitational interaction between planets.The unique architecture characteristic of the given planetary system is determined during this evolution. The planetesimal hypothesis also raises unanswered questions. One of them is the one meter limit, another is the issue of formation and fast migration of giant planetary cores. In the lectures, we will also discuss potential solutions to these problems, which are the most intensively researched areas of planet formation theory. The lecture topics are the following: - observation and characterization of exoplanet systems, - special case: Solar System, - observation, characterization and physics of protoplanetary accretion disks, - evolution of protoplanetary disks, - formation of planetesimals, - formation of Earth-type planets, - formation of gas giants, - planet-disk and planet-planet interactions, migration, - early evolution of planetary systems, the Nice model.

FIZ/2/105 Chaos detection methods in Hamiltonian systems – Application to celestial mechanics

Chaos in Hamiltonian sytems: Standard map(s) as 2D, 4D, 6D discrete Hamiltonian systems; Concept of the Poincare map of a continuous Hamiltonian system, The surface of section; Poincare maps of the Sitnikov problem, restricted three-body problem; Analogy between the surface of sections of continuous systems and discrete symplectic mappings.*Analysis of the phase space of discrete and continuous Hamiltonian systems:* Fixed points - periodic orbits; Stable/unstable periodic orbits and the corresponding elliptic/hyperbolic fixed points of symplectic maps; Numerical characterisation of stability: calculation of stability indices. *Appearance of chaos in Hamiltonian systems:* The stable and unstable invariant manifolds of hyperbolic fixed points; Homoclinic/heteroclinic intersections; Bounded chaotic layers, large chaotic sea. *Mathematical foundation of the chaotic phenomena in Hamiltonian systems*: The Kolmogorov-Moser-Arnold theorem; The Poincare-Birkhoff theorem; Diffusion of orbits in the Chirikov regime; Arnold diffusion; Nekhoroshev-stability. *Quantifying chaos*: The Lyapunov characteristic exponents; The finite-time Lyapunov indicator. *Fast chaos indicators and their calculation for symplectic maps*: The fast Lyapunov indicator (FLI); The relative Lyapunov indicator (RLI); Smallest/generalized alignment indices (SALI/GALI); MEGNO.

Application of the fast chaos indicators to low dimensional continuous Hamiltonian systems: The Sitnikov problem; The restricted three-body problem; The few-body problem (motion of minor bodies in the Solar System) Chaos indicators in continuous multi-dimensional Hamiltonian systems: The Fermi-Pasta-Ulam problem

Stellar astrophysics

FIZ/2/028 Binary stars I

A review of the history of binary star research; Gravitational equipotential surfaces in binary stars; Classification of binary stars based on their Roche lobes; Motion of binary stars (two-body problem + special perturbations); O-C diagrams and their analysis; Observational methods for measuring variations in orbital period; Physical reasons behind the variations in orbital period;

FIZ/2/033 Active stars I

The Sun as a prototype of stellar magnetic activity. Sunspots and starspots, butterfly diagram, Wolf number, Maunder mininum. Spectroscopic activity criteria, Ca II H and K lines, Mg II h and k lines. The timescales of the magnetic activity of the Sun and other stars. Rotational modulation of activity indicators. Solar and stellar flares. Flare activity of RS CVn stars.

FIZ/2/036 Nucleosynthesis

The course is devoted to the synthesis of chemical elements in the Universe.

Syllabus: basics of nucleosynthesis using nuclear physics; the thermodynamics of the early Universe; Big Bang nucleosynthesis; hydrogen-burning stars; solar neutrinos; nucleosynthesis in large mass stars; synthesis of elements heavier than iron; further nucleosynthesis processes.

FIZ/2/046 Recent results in asteroseismology

Pulsating variable stars are key components of modern astrophysics. They are the test objects of stellar evolution models, and are calibration tools of absolute physical parameters. Asteroseismology is our most important tool for "taking a look" into the inside of stars. Despite their vital role, even now we still don't know and understand everything concerning the behavior of pulsating stars. For example, the modulation of RR Lyrae stars, the so-called Blazhko effect. Although we have known about it for 100 years, we still haven't found a satisfying explanation for this phenomenon. The mode selection of multi-mode stellar pulsation is also, to this day, an open question, we cannot explain the amplitudes of observed modes, and changes thereof. The investigation of solar-type oscillations is one of the most current research topics. The research of white dwarves is another successful, modern branch of asteroseismology.Variable star research has traditionally been at the forefront of Hungarian astronomical/astrophysical research, with internationally recognized results. The aim of this course is to introduce students to this research work, and thus provide a needed addition to the university curriculum so that there is a suitable next generation of Hungarian variable star researchers. During the course, we review the phenomenology and characteristic behavior of different types of pulsating variable stars, and we study the theoretical background of pulsation. We emphasize the types that PhD students attending the course are investigating for their theses. We review unsolved questions about the behavior of stars, and the most recent asteroseismological advances concerning photometry, spectroscopy and the theory.

FIZ/2/061 Binary stars II

Physics of dwarf novae and accretion disks; Novae and type I supernovae; High energy phenomena in binary star systems, X-ray binaries; Light curve modelling; Computer codes, software products and algorithms for modelling binaries; Evolutionary tracks of binary stars; Binary stars in the Milky Way and in other galaxies; Strange binary stars and some special binaries in detail

FIZ/2/066 Active stars II
Direct measurement of the magnetic field of stars. Zeeman effect, Lande factor, Babcock's method, Robinson's method. Active regions on stars, convection, rotation, primordial fields. Relationship between age and activity. HK project at Mount Wilson. Frequency distribution of the magnetic activity of solar-type stars. Doppler imaging of stellar surfaces.

FIZ/2/070 Accretion processes in star formation
The formation of stars is a central problem in modern astrophysics. One of the most important processes that create a main-sequence star from a dense molecular cloud is accretion, the accumulation of material from the circumstellar region, which gives the protostar its final mass. Matter is generally accreted from a circumstellar disk, and the accretion rate is determined by the structure and temperature distribution of the disk, and the magnetic field of the young star. To this day, the exact details of the process are not known. During the semester, we review observational signs of accretion, measurement options for the accretion rate, the physical theory of accretion disks (analytical models, numerical simulations), and finally we discuss young eruptive stars (FU Orionis and EX Lupi type objects) where the temporary acceleration of accretion causes sudden brightening.

FIZ/2/080 Structure of compact stars
We call compact objects the generally stable, cold final states of stellar evolution: dwarfs, neutron stars, hyperon stars, quark stars and black holes. These extreme stars have roughly a few times the mass of the Sun, their size is on the order of 1-10 km, therefore their density can be even higher than the density of a nucleus. They are created from large mass stars via supernova explosions, high energy processes. For their description one should apply nuclear models or quantum chromodynamics - describing the strong interaction - together with gravitational theory. From the observational point of view, the investigation of compact stars is difficult, because they do not, or barely emit (direction-dependent) electromagnetic radiation, thus in most cases can be detected only indirectly.
During the lectures we learn about the physical description, models and detectability of these extreme compact objects.

FIZ/2/093 Lightcurve variability in young stars
In view of the most recent research results, we introduce the observable photometric and spectroscopic variability of young star - protoplanetary disk systems, from the UV to the far infrared wavelengths, discussing the reasons behind the changes (change in the accretion rate, circumstellar extinction, disk structure), the timescales, and the types of young variable stars.We examine in detail the following types, mainly based on the newest findings of our group: Eruptive young stars: FU Orionis (FUor) and EX Lupi (EXor) type stars; V1647 Ori and similar objects (PV Cep, V1180 Cas) Variable extinction stars: UX Orionis type stars (SV Cephei, V517 Cygni).Binary systems with a common disk: KH15D and similar objects.

FIZ/2/099 Chapters from the theory and observation of multiple star and planet systems I
Historically, a substantial part of our astrophysical knowledge has been derived from observing close binary star systems. Thus, their observation has always been of special significance. Today it has become obvious both from theoretical considerations and measurements that close binaries must form, and must have formed from multiple star systems. Such systems can be considered fundamental examples even today, from multiple perspectives. Thanks to them, star formation and stellar evolution models can be tested, and it is possible to directly investigate, among others, the internal mass distribution of stars, the viscosity of stellar material, and numerous other parameters. During the course, we introduce the theoretical models of the formation of close multiple star systems and planet systems, and we discuss the verifiability of the models based on observational data. In connection to this, students will be familiarized with observational methods used for these systems, such as polarimetry, spectroscopy, high resolution optical and radio interferometry astronomy, and also with supplementary data analysis tools such as the eclipsing O-C diagram and the radial velocity curve. Furthermore, we will introduce the analytical equation of motion of hierarchical systems, and practical applications thereof.

FIZ/2/100 Chapters from the theory and observation of multiple star and planet systems II
Historically, a substantial part of our astrophysical knowledge has been derived from observing close binary star systems. Thus, their observation has always been of special significance. Today it has become obvious both from theoretical considerations and measurements that close binaries must form, and must have formed from multiple star systems. Such systems can be considered fundamental examples even today, from multiple perspectives. Thanks to them, star formation and stellar evolution models can be tested, and it is possible to directly investigate, among others, the internal mass distribution of stars, the viscosity of stellar material, and numerous other parameters. During the course, we introduce the theoretical models of the formation of close multiple star systems and planet systems, and we discuss the verifiability of the models based on observational data. In connection to this, students will be familiarized with observational methods used for these systems, such as polarimetry, spectroscopy, high resolution optical and radio interferometry astronomy, and also with supplementary data analysis tools such as the eclipsing O-C diagram and the radial velocity curve. Furthermore, we will introduce the analytical equation of motion of hierarchical systems, and practical applications thereof.

FIZ/2/114 Pulsation theory
The course guides us through the mathematical and physical fundamentals of pulsation theory, the linear description of pulsation, as well as nonlinear processes. We briefly discuss numerical modeling methods of stellar pulsation. We demonstrate the use of pulsating variable stars in solving various astrophysical problems. We learn about the excitation mechanisms of pulsation and the most important pulsating variable star classes. Great emphasis is given to the description and understanding of solar-like oscillations. The history and most important results of helioseismology is also discussed. Last but not least, we highlight the importance of the 'asteroseismology revolution' induced by ultra-precise space photometric missions (CoRoT, Kepler).

FIZ/2/116 Observing pulsating variable stars
We discuss the development of, and the current problems in modern observational asteroseismology. We introduce the most advanced instruments and tools of the observational data acquisition and analysis in pulsating variable star studies. We also plan hands-on exercises with the widely used data reduction and analysis software tools (e.g. IRAF, MuFrAn, Period04, FAMIAS, various Python utilities).

Galaxies and cosmology

FIZ/2/015 Inflationary cosmology
Einstein equations, Boltzmann equation for relativistic matter. Inflationary initial conditions, field theoretical models of inflation. The evolution of dark matter. The cosmic microwave backround.

FIZ/2/025 The physics of interstellar matter I

Propagation of electromagnetic radiation: flow equation, solving the flow equation; Einstein coefficients, solving the flow equation with Einstein coefficients, stimulated emission.
21-cm radiation of neutral hydrogen: formation, propagation, role in mapping out the Galaxy.
Molecules in interstellar matter: rotational, vibrational transitions, optical pumping, masers, CO, NH3, H2 molecules.

FIZ/2/027 Dynamics of stellar systems I
General properties of galaxies. Isophotes, equivalent radius, Holmberg radius, effective radius, core radius. Schechter luminosity function. Spectrum and kinematics. Elliptical galaxies and shells. Isophote shapes. Luminosity profiles, de Vaucouleurs profile, Hubble profile. Giant, dwarf and compact galaxies. Kinematics, Faber-Jackson relation, Davies relation. Color indices, spectrum, chemical composition, Mg2 index.

Globular cluster system, globular cluster specific frequency. Interstellar matter in elliptical galaxies, halo gas. Dark matter halo. Kinematically detached subsystems: Ep galaxies, disks. Galactic disks. S0 galaxies. Exponential disks, Freeman law. The vertical structure of the disk. Disk kinematics, Tully-Fisher relation.

FIZ/2/037 Current research results in interstellar matter and star formation I

The objective of this seminar is to review and discuss the latest papers about interstellar matter and star formation. Main topics: (1) The structure of star-forming regions, interstellar matter, (2) Pre-main-sequence stars, accretion disks, (3) Protostars and their surrounding molecular clouds.

FIZ/2/047 Extragalactic astrophysics II

The larger part of the lectures is devoted to galactic dynamics: the collisionless Boltzmann equation, the structure of elliptical galaxies, and the vertical and horizontal structure of the disk of spiral galaxies. In the last three lectures we briefly study some more questions of extragalactic astrophysics: the large-scale structure, galaxy clusters, and quasars. Further interesting topics: dark matter searches, redshift surveys, etc.

FIZ/2/058 The physics of interstellar matter II

Interstellar dust: dust models, optical extinction, observability, determining the dust temperature.
Phases of the interstellar medium (ISM), role of shockwaves in creating the hot phase: composition distribution of the ISM, heating mechanisms, cooling function, ISM in the Galaxy, the types, sources and evolution of shockwaves, HII zones.Theory of star formation, pre-main sequence evolution of stars: virial theorem, Jeans length, stability, collapse of an isolated cloud, isothermal collapse of gas, D-flash, embedded objects, Class O-3 objects, HH objects.

FIZ/2/060 Dynamics of stellar systems II

Two types of S0 galaxies: lenticular galaxies and anemic disks. Gas in S0 galaxies. Bends. Barred galaxies, and their frequency distribution as a function of the size of the bar. Connection to lenticular galaxies and oval disks. Luminosity profile. Kinematics, "temperature". The origin of the bar: spontaneous instabilities in the disk. Stability criteria. Spiral galaxies. Grand design and flocculent spirals. Logarithmic spiral curve. Inclination, method of spiral rectification. Fine structure of spiral arms. Kinematics, spiral perturbations of the galactic velocity field. The origin of the spiral structure. Short- and long-wavelength modes, corotation. Rings in spiral galaxies.

FIZ/2/074 The distant Universe

(The observation of extragalactic background and its physical basis)

- Foundations of studying distant galaxies:
    - Equations of high-z physics
    - Structure formation at high redshifts
    - Energy release mechanisms in galaxies
    - Methods for the statistical description of quasi-random radiation fields
- Cosmic microwave background (CMB):
    - The discovery of CMB and CMB measurements up to now
    - CMB and the Big Bang
    - Physics of the „last scattering”
    - Origin of anisotropies
    - Results from CMB observations
- Cosmic Infrared Background (CIB):
    - Discovery of CIB and recent measurements
    - Observational methods:
    - Absolute photometry
    - Source counts
    - Study of fluctuations
    - Sources of CIB: infrared galaxies and their physics

- Cosmic optical and UV background:
    - Properties of sources and observations
- High energy backgrounds:
    - Cosmic X-ray background – the physics of the sources, observations
    - Cosmic gamma-ray background – the physics of the sources, observations

FIZ/2/076 Chapters from modern astronomy and cosmology

The science of astronomy and cosmology is advancing at such a pace that over the course of several years almost completely new areas appear (and sometimes disappear). A decade ago we didn't know of dark energy, in a few years new information might replace it with something else. There are topics that may not make it into the curriculum, not only because they are new, but because there is no continuing interest for them. However, from time to time such areas may be worth discussing in more detail, depending on currently active PhD students and research topics. The goal of this seminar is to study such topics that are new or that are missing from the curriculum, based on a book or review article, with a changing focus every semester, and with professors and PhD students working together.

FIZ/2/119 Data mining in astronomy

The purpose of the course is to introduce students to the fundamental methods of astronomical data modelling, advanced statistics and data mining. Projects are assigned primarily from the fields of extragalactic astronomy and cosmology and are to be solved using real observational data. Projects can be solved using the data analytic software of choice (e.g. Python, Matlab, Octave, IDL). Course credits are obtained by finishing assignments and submitting report. The course is primarily intended for astronomy and physics students with appropriate previous knowledge.

FIZ/2/120 Stellar and galaxy populations

The special course attempts to give insight into the theory and results of spectroscopic and statistical anlysis of galaxies and galaxy populations. Building from the basics (observational spectroscopy, stellar spectroscopy) lectures go as far as theory of complex models of galaxies (population synthesis, active galaxies, galactic evolution).

FIZ/2/121 Active Galactic Nuclei

Active galactic nuclei (AGN) are among the most energetic and spectacular objects in the sky. They reside in the centres of galaxies and are often so luminous that they outshine their entire host galaxy. In this lecture series we will discuss AGN in considerable detail, addressing their taxonomy, the physics of the various building blocks of AGN including the accretion disks and dusty tori around the central supermassive black holes, their time evolution and their roles in galaxy formation and evolution.

FIZ/2/122 Black hole astrophysics

Black holes are the ultimate prisons of the Universe, regions of spacetime where the enormous gravity prohibits matter of even light to escape to infinity. Yet, matter falling toward the black holes may shine spectacularly, generating the strongest source of radiation. These sources provide us with astrophysical laboratories of extreme physical conditions that cannot be realized on Earth. This course reviews the astrophysical phenomena related to black holes and the related modern research fields. We discuss the properties of general relativistic black hole spacetimes and the hydrodynamical accretion flows in such environments and its observables. We review the theories and observations of black hole formation and evolution from stellar to supermassive scales.

FIZ/2/123 Selected chapters from the compact-star structure investigation

The course aims to familiarize the students with the modeling of the interior of compact stars (such as: neutron stars, quark stars, black holes, pulsars). During the semester, we will provide overview of the recent scientific results and observations related to the neutron stars and pulsars. We investigate the multi-wavelength measurements of compact stars, in addition to the connection between the inner structure and their electromagnetic/gravitation signals. Topics: extreme stars, superfluidity/superconductivity in neutron stars, glitches, crust-core models, gravitational signals of neutron star mergers, I-LOVE-Q. Participation in this course pre-requires the “Investigation of compact star (interior)” special course.

Program III: Statistical Physics, Biological Physics and Physics of Quantum Systems

Head of the program: Dr. Jenő Kürti

Course descriptions

(all optional classroom courses for 6 credits, cannot be repeated, credits to be obtained: 48)

FIZ/3/003 Statistical physics of biological sytems

An introduction to the properties of systems displaying scaling behavior, basics of fractal geometry, simple growth models, percolation theory, self-organized critical systems and their models. Geometry of bacterial colonies: microbiological background, morphology diagram, models of colony growth. Synchronization in biology: integrate-and-fire modlels, the Kuramoto model. Networks: types of equilibrium graphs, models of growing graphs, processes on graphs, graph modules. Collective motion: phenomena, basic model, collective motion of humans.

FIZ/3/004 Fractal growth

Fractal geometry in nature, fractal dimensions, types of fractals (isotropic, self-affine and fat fractals), multifractals, computer models of growth phenomena, invasion percolation, random walks, theoretical description and simulation of diffusion-limited aggregation, multifractality, growth of self-affine surfaces, the role of fluctuations and surface tension, continuum description of fractal growth phenomena, a review of experiments.

FIZ/3/005 Theoretical evolutionary biology

A general concept of fitness and its specific realizations. Basics of population genetics. Neutral and molecular evolution. Elementary ecological models. Ecology and frequency-dependent selection. Adaptive dinamics. Evolutionary game theory. Speciation. Macroevolution. Modeling the biosphere as a self-organizing critical system.

FIZ/3/008 Pattern formation in complex systems

Introduction, definitions: spatial and/or temporal patterns in systems far from equilibrium; homogeneous, ordered (periodic) and chaotic states. Theoretical description: methods, dissipative dynamics, stability and bifurcations, linear stability analysis and nonlinear basic states. model equations. Nonlinear behavior in classical mechanics. Non-linear behavior in chemistry (Bjelousov-Zhabotinsky and Turing instabilities) Shear induced (flow) instabilities: Taylor-Couette, Rayleigh, Rayleigh-Taylor, Kelvin-Helmholtz, Benard-Marangoni instabilities. Thermally driven convection: Rayleigh-Benard instability. Role of anisotropy; thermal convection in liquid crystals. Electroconvection. Interfacial patterns: viscous fingering, linear stability analysis. Non-equilibrium solidification: dynamics of a solid-liquid interface. Non-linear optics. Computer simulation methods: DLA, phase-field model. Experimental techniques: shadow graph, image processing.

FIZ/3/009 Liquid crystals and polymers

Introduction: mesomorf behaviour, mesogene compounds, classification of liquid crystals Statistic theories: mean-field approximation, Landau-, Onsager and Maier-Saupe theories, description of phase transitions, order parameter Experimental molecular dynamic methods: dielectric spectroscopy, NMR, neutron scattering Continuum description of nematic and colesteric liquid crystals:Deformational free energy, effect of external fields, surface interactions, Freedericksz transition, field effects in colesteric liquid crystals. The Ericksen-Leslie continuum theory:balance equations, reversible, irreversible processes, viscosity measuring, Lehmann-effect.Optical properties of liquid crystals:Polar light, dual reflection, selective reflection, optical rotation, adiabatic light propagation, dicroism, reorientation with light, termooptics. Ferroelectric liquid crystals:Polarisation, flexoelectricity, spontanious polarisation, tvisted smectic C* phase, SmA*-SmC*

Landau theory of phase transition, ferroelectric switch, elektromechanical effect, antiferroelectric phase, electroclinic effect. Piro- flexo and ferroelectricity Liotrop liquid crystals, membranes, dual layers, biological aspects Liquid crystal polymers Application of liquid crystals: heat-mapping,structure of displays, display effects, matrix displays, color displaying, light driven devices.

FIZ/3/010 Sensory biophysics
The goal of this course planned for two semesters is to overview the functionality of the human and animal sensory organs (or those of plants in some special cases) and the environmental-physical signals (optical, acoustic, electric, magnetic, gravitational, thermal) that can be perceived with these organs, furthermore for what purpose the animals/humans/plants use them. All chapters of the lecture consists of four parts: (1) formation, occurrence of a given physical signal, (2) the perception of the given signal, (3) human/animal emission of the signal, (4) physiological/behavioral role of the signal. Main topics of the course: (i) color vision: perception of colors – formation of color patterns; (ii) perception of ultraviolet light – UV light in the environment; (iii) perception of infrared light; (iv) polarization vision: perception of polarized light – polarization patterns; (v) heat perception – heat control; (vi) bioluminescence: active light emission; (vii) bioacoustics: emission of souns – hearing (audible, ultra- and infrasounds); (viii) perception of the electric field; (ix) perception of the magnetic field; (x) perception of the gravitaional field and its effects – biomechanics.

FIZ/3/012 Chaos in mechanical systems
Investigation methods of complicated motions, main features of chaos. Period doubling bifurcations in dissipative systems. Structure of the chaotic regime of one-dimensional mappings. Two-dimensional mappings. Fractal structure of attractors of differential equation systems, basic types. Intermittency, transition from quasiperiodic motion to chaos. Transient chaos. Phase space structure of integrable and non-integrable conservative systems, Kolmogorov-Arnold-Moser theorem, perturbation theory. Standard map, decay of the last KAM torus, Arnold's diffusion. Billiards, chaotic scattering**.**

FIZ/3/013 Quantum chaos in mesoscopic systems
Billiards, Random matrix theory: symmetries, universal classes, Gaussian distribution, mixture distribution of eigenvalues, determine density of states with Coulomb gas method and Green function, nearest-neighbor distribution, Scars: theory and experiments, Random matrix theory applied to quantum transport: basics of experiments, scattering and transferring matrices: basic properties, low localization conductivity fluctuation.

FIZ/3/015 Carbon Nanostructures
Discovery of C60, historical survey, isolated cage like molecules.
Properties of C60 in gas- liquid- and solid phases.
Doped fullerenes, fullerites.
Fullerene polymers.
Carbon nanotubes: geometrical, vibrational and electronic properties.
Applications.

FIZ/3/016 Macromolecules
Flexible chain polymers: polymerization, polycondensation, distribution functions of polymers, basics of conformation analysis, local and global conformations, effect of cooperativity, statistical description of ideal polymers, the theta state, rubber flexibility. Conjugated carbon-chained polymers: conjugated constructs, linear chain – one dimension instabilities, effect of doping, insulator-metal transitions, solitons, polarons, bipolarons. Biological polymers: spatial structure of cellulose, analysis of protein structures with energetic calculations and statistical methods, theoretical analysis of trans-membrane proteins, spatial structure of DNA and its flexibility.

FIZ/3/017 Physics of environmental flows
In this introductory course we summarize the basic physics of the largest scale flow phenomena in the

atmosphere and oceans. Necessary background: classical hydrodynamics.
Subjects: Rotating homogeneous fluids, Coriolis force, Rossby number, Navier-Stokes equation in rotating reference frame, dimensionless representation, Froude number, dynamic pressure, geostrophic equilibrium, Taylor-Proudman theorem linearized equations, inertial oscillation, inertial waves, dispersion, phase and group velocities, shallow water equations, potential vorticity conservation, free surface Rossby waves, Kelvin waves at closed boundaries, surface curvature: f-plane and beta-plane approximations, planetary Rossby waves, finite viscosity: Ekman number, Ekman spiral, Ekman transport, stratification, Brunt-Vaisala frequency, adiabatic atmosphere, potential temperature, potential density, Boussinesq approximation, internal waves at continuous stratification, equations for two layer fluids, geostrophic solutions, Margules formula, thermal wind, baroclinic instability.
Literature: 1) B. Cushman-Roisin: Introduction to Geophysical Fluid Dynamics (Prentice-Hall, London, 1994) ISBN: 0-13-353301-8 2) J. Pedlosky: Geophysical Fluid Dynamics (Springer, New-York, 1987) ISBN: 0-387-96387-1

FIZ/3/018 Application of chaos theory
We provide a concise summary of nonlinear methods developed from theories of dynamical systems. Emphasize on computer exercises. Necessary background: introductory courses on chaos and nonlinear dynamics.Subjects: - Linear tools, testing for stationarity, linear filters, linear predictions, phase space methods, delay reconstruction, false neighborhood, Poincare surface of section, recurrence plots, simple nonlinear prediction, nonlinear noise reduction, measuring Lyapunov exponent, attractor geometry and fractals, correlation dimension, interpretation and pitfalls, temporal correlations, scaling laws, detrended fluctuation analysis, testing nonlinearity with surrogate data, nonlinear statistics, transients, intermittency, quasi-periodicity.
Literature: H. Kantz, T. Schreiber: Nonlinear Time Series Analysis (Cambridge University Press, Cambridge, 2004) ISBN 0-521-52902-6

FIZ/3/019 Modeling traffic in communication networks

Goals: to study the statistical properties of traffic in modern communication networks.
Types of communication networks and their basic properties from the point of view of traffic.
Poisson modeling of classical telephone systems. Markovian models. Queuing models and Erlang's formula.
Traffic modeling in the Internet: heavy tailed distributions, Long Range Dependence, scaling and Hurst exponents. Fractal traffic models, On-Off processes, file length distributions. Measuring traffic in real and simulated networks. Round Trip Time, Packet Delay and Packet Loss statistics, 1/f noise, congested-non congested phase transition. Protocols and traffic TCP as a dynamical system, modeling small networks with stochastic maps. Traffic modeling with network simulator. Routing and traffic. Ad-hoc networks and load on random graphs.
Literature:
Kleinrock, L., Queueing Systems, Volume I: Theory, Wiley Interscience, New York, 1975
Kocarev L., Vattay G., Complex Dynamics in Communication Networks, Springer Verlag, 2005
Recommended literature
Few publications of the Lecturer:
A. Fekete, G. Vattay and A. Veres, Improving the 1/sqrt(p) law for single and parallel TCP flows In Teletraffic Engineering in the Internet Era, ed.: J.M. de Souza,N.L.S. da Fonseca, E.A.S. Silva, North-Holland Amsterdam (2001)
A. Veres, Zs. Kenesi, S. Molnar, and G. Vattay, On the Propagation of Long-Range Dependence in the Internet ACM SIGCOMM 2000 and Computer Communication Review 30, No 4, 243-254 (2000)
A. Fekete and G. Vattay, Self-Similarity in Bottleneck Buffers Proceedings of Globecom, (2001)

FIZ/3/021 Statistical physics of polymers and membranes
Polymers: ideal chains (lattice chain, Gaussian chain, freely jointed chain, bead-rod chain, worm like chain); Flory model of excluded volume, interaction with solvent; Langevin dynamics, Rouse model, Zimm model;

scaling properties (semi-dilute solutions, confinement, weak adsorption); electrophoresis.
Membranes: physical properties, elastic models; Monge representation, thermal fluctuations, surface tension; membrane tubes; membrane adhesion; interaction with the cytoskeleton.

FIZ/3/022 Mesoscopic superconductors
In this course we give a review of the present status of the mesoscopic superconductivity.
Bogoliubov - de Gennes equation. Andreev reflection, proximity effect. Currents in superconductors. Scattering at normal-superconducting interface. Conductance of normal-superconducting hybrid systems. Superconducting-normal-superconducting systems: mesoscopic Josephson junctions. Gauge transformation of the Bogoliubov - de Gennes equation. Excitation spectrum for Andreev billiards.
Literature:
P. G. de Gennes: Superconductivity of Metals and Alloys (Benjamin, New York, 1996)
F. Andreev, Zh. Eksp. Teor. Fiz. 46, 1823 (1964), [Sov. Phys. JETP, 19, 1228 (1964)]
A. Abrikosov: Fundamental of the Theory of Metals, (Elsevier Science Publishers, Amsterdam, The Netherlands, 1988)
M. Tinkham: Introduction to Superconductivity, (McGraw-Hill, Inc., New York, 1996)
J. B. Ketterson and S. N. Song: Superconductivity, (Cambridge University Press, Cambridge, 1999)
C. J. Lambert and R. Raimondi, J. Phys. Condens. Matter 10, 901 (1998)
C. W. J. Beenakker, in Mesoscopic Physics, Les Houches Summer School, edited by E. Akkermans, G. Montambaux, J. L. Pichard, and J. Zinn-Justin (Elsevier Science B. V., Amsterdam, 1995); C. W. J. Beenakker, Review of Modern Physics 69, 731 (1997)
M. Brack and R. K. Bhaduri: Semiclassical Physics, (Addison-Wesley Pub. Co., Inc., Amsterdam, 1997)

FIZ/3/023 Physics of mesoscopic systems II.
In this course we give a review about the most relevant experiments and theories related to mesoscopic systems. The course is based on the course of Mesosopic Systems I.
Integer quantum Hall effect. Fractional quantum Hall effect. Quantum point contact. Coulomb blockade. Persistent current. Quantum dots, artificial atoms. Antidot lattice, classical and quantum chaos. Lateral magnetic super lattice (magnetically modulated mesoscopic systems). Photonic crystals. Shot noise. Spintronics.
Literature:
Supriyo Datta: Electronic Transport in Mesoscopic Systems (Cambridge Studies in Semiconductor Physics and Microelectronic Engineering) (Paperback)
C. W. J. Beenakker and H. van Houten in Quantum Transport in Semiconductor Nanostructures, Solid State Physics, Vol. 44, pp. 1-228, edited by H. Ehrenreich and D. Turnbull, (Academic Press, Inc., Boston, 1991)
Y. Imry: Introduction to Mesoscopic Physics, (Oxford University Press, Oxford, England, 1997)
D. K. Ferry and S. M. Goodnick: Transport in Nanostructures, (Cambridge University Press, Cambridge, 1997)
T. Heinzel: Mesoscopic Electronics in Solid State Nanostructures,(Wiley-VCH GmbH & Co. KGaA, Weinheim, 2003)
H-J. Stöckmann: Quantum Chaos, An Introduction,(Cambridge University Press, Cambridge, 2000)
C. W. J. Beenakker and C. Schönenberg: Quantum Shot Noise, Pysics Today May 2003, and References therein
D. Weiss, G. Lütjering, and K. Richter: Chaotic Electron motion in Macroscopic and Mesoscopic Antidot Lattices, Chaos, Soliton, & Fractals, Vol. 8, pp. 1337-1357
R. B. Laughlin: Noble Lecture: Fractional quantization, Review of Modern Physics, Vol. 71, 863 (1999) and References therein; H. L. Stromer: Noble Lecture: The fractional quantum Hall effect, Review of Modern Physics, Vol. 71, 875 (1999)
Spintronics and Quantum Computation, edited by D. D. Awschalom, D. Loss, and N. Samarth (Springer, Berlin, 2002) and References therein ; S. A. Wolf, D. D. Awschalom, R. A. Buhrman, J. M. Daughton, S. von Molnár, M. L. Roukes, A. Y. Chtchelkanova and D. M. Treger, Science Vol. 294, 1488 (2001)

FIZ/3/025 Trapped atomic systems
The goal of this course is to overview the modern experiments with trapped bosons and their theoretical background. The topics include:
Experiments with trapped ultracold boson gases. Bose condensation in trapped non-reacting model. The Gross-Pitevskii equation and its solution at zero temperature. Thomas-Fermi approximation for the condensatum. Density excitations, Bogoliubov equation. Quantum hydrodinamics for density wave modes. Atomic laser. Vortexes in quntum gases.

FIZ/3/027 Extreme statistics and their applications
The problem of extremal value fluctuations is introduced through empirical statistical problems like water level or appliance failure records. Then the classical basic extremal "universal" limit classes, Gumbel, Frechet, and Weibull are introduced. They are thoroughly, albeit non-rigorously, analyzed with regard to finite size effects, namely, the dependence of the empirical average, the variance, and the correction to the universal asymptote on the number of variables N. Treated are also the distribution of the k-th maximum, and the joint statistics of the first k maxima. The emergence of extreme value statistics in surface fluctuations, like the width (roughness) statistics and extremal excursions of Brownian and more general random walks are discussed, in the light of most recent results.

FIZ/3/028 Computer simulations in statistical physics
Introduction to simulation technics. Generation and testing of random numbers. Initial and boundary conditions. Data collection and reduction, finite size scaling. Geometrical problems, percolation, cluster statistics, polimer models. Monte-Carlo (MC) method in hamiltonian systems. Priority sampling. MC in canonical and other ensembles. Ising model. Special MC technics. Slowing down problems. Multispin coding. cluster-algorithms. Histogram technic. MC renormalization group. Optimization. Simulated heat treatment. Genetical algorithms. Molecule dynamics (MD). Algorithms, time stepping and event-triggered methods. Thermostat. Non-equilibrium MD. Growth models. Physical meaning of models defined by algorithm. Numerical solution of stochastic differential equations. Measuring of fractal dimension.
Cellular automata. Grading. Hydrodinamical cellular automatons. Self organizing critical systems. Game theory models.

FIZ/3/029 Introduction to quantum optics
The interaction of an idealized two-level atom with classical electromagnetic field.
Quantization of the electromagnetic field in vacuo, remarkable quantum states; spontaneous emission;
A quantum theory of dissipation: Schrödinger picture;
A quantum theory of dissipation: Heisenberg-Langevin picture;
Fluorescence resonance;
Semiclassical laser theory;
Nonlinear optics: Second Harmonic Generation;
Interaction between atom in cavity and radiological field: Jaynes-Cummings model;

FIZ/3/030 Coherent control of quantum systems
Coupling of atomic transitions with electromagnetic field;
Control of the quantum state of atoms by incoherent and coherent light;
The role of dissipation and dephasing in control processes;
Coherent control of the quantum state of degenerate, multilevel atoms;
Robust control mechanisms;
Reconstruction of the quantum state of atoms;
Control of the center of mass motion of trapped ions;
Control of the vibrational wave packet of molecules;

FIZ/3/032 Phase transitions

Basic concepts and facts. A survey of examples. Mean-field approximation. Ising-model. Heisenberg-model, Mermin-Wagner theorem. Other models. Critical exponents: measurements, classical theory, high temperature series. The static scaling hypothesis and consequences. Renormalization group transformation. Fixed point, scaling, universality. Construction of the transformation in real space and in wavenumber space. A survey of results. Dynamical critical phenomena: conventional theory, dynamical scaling hypothesis, examples.

Recommended texts: L.D. Landau, E.M. Lifsic: Elméleti fizika V. (Tankönyv-kiadó, Budapest), E.H. Stanley: Introduction to Phase Transition and Critical Phenomena (Clarendon Press, Oxford 1971), S.K. Ma: Modern Theory of Critical Phenomena (Benjamin, London 1976).

FIZ/3/033 Non-equilibrium statistical physics

Linear response, noise measurement, inelastic scattering, Langevin and Fokker-Planck equations, dynamics of phase transitions, master equations and their applications to quantum optics, spin echo, transport in gases, models of complex systems.

Recommended texts: Statistical Physics II -- Nonequilibrium Statistical Mechanics

Authors: Kubo, Ryogo, Toda, Morikazu, Hashitsume, Natsuki

FIZ/3/034 Mathematical methods in quantum chemistry I.

Second quantized approach: wave functions, operators, calculation of matrix elements, density matrices, connection with the bra-ket formalism. Model Hamiltonians. Practice of the Hartree-Fock-Roothan calculations.

Recommended texts: Kapuy E., Török F.: Az atomok és molekulák kvantumelmélete (Akadémiai Kiadó, Budapest 1975), Mayer I.: Fejezetek a kvantumkémiából (lecture notes), G.Náray-Szabó, P. Surján, J. Ángyán: Applied Quantum Chemistry (Reidel/Cluver-Akadémiai Kiadó, Dordrecht-Budapest 1987).

FIZ/3/035 Many-body problem I.

Necessary background: Quantum mechanics, Statistical physics.

The course develops the quantum theory of many particle systems. The lectures of the first semester are devoted to normal systems using the temperature Green's function technique. The first part is devoted to the general formalism, while the second part concentrates on the electron gas. Occupation number representation: creation and annihilation operators. Definition of the temperature Green's function in grand canonical ensemble. Expression of equilibrium physical quantities in terms of them. Perturbation theory, Wick's theorem, Feynman diagrams. Self-energy and the Dyson equation. Hartree-Fock approximation.

Electron gas in homogeneous positive background. Calculation of the correlation energy. Spectral function, retarded Green's function, analytic properties, elementary excitations. Density propagator and its spectral function: perturbation theory and analytic properties. Collective excitations in the electron gas (the plasmon). The problem of stability of normal systems.

Literature:

E.M. Lifsic and L.P. Pitaevskii: Statistical Physics, Part 2 : Volume 9 (Pergamon, 1980)

A.L. Fetter and J.D. Walecka: Quantum Theory of Many-Particle Systems (McGraw-Hill, 1971)

P. Szépfalusy and G. Szirmai: Véges hõmérsékleti soktestprobléma (lecture notes available in Hungarian under http://www.complex.elte.hu/~szirmai/SP.pdf).

FIZ/3/036 Chaotic Mechanics I.

Chaotic motions, examples, the phase space. Fractal objects. Regular motion, instability, hyperbolic points, stable and unstable manifolds. Driven dynamics, stroboscopic maps. Chaos in dissipative systems, the baker map, driven oscillators, the indicators of chaos, the Lyapunov exponent, the water wheel. Chaos in conservative systems, the KAM theorem, irreversibility.

FIZ/3/037 Environmental fluid hydrodynamics II. EA

Stratified fluids. The Boussinesq approximation, the internal Froude number. Internal waves, mountain waves, normal modes. Two-layered media. Supercritical flows, hydraulic jump, shockwaves. Gravity waves, internal solitons, Kelvin-Helmholtz instability. Rotating multi-layered fluids. Waves in two-layer shallow fluids. Geostrophic balance. Rossby waves. Continuously stratified media, the baroclinic instability.

FIZ/3/039 Statistical properties of chaos

Phase space, Poincare map, Liouville equation, Frobenius-Perron equation, Hamiltonian system. Ergodicity, mixing, convergence to the equilibrium. Simple attractors, hyperbolicity, strange attractor, the limit of strong dissipation, ergodic invariant measure. Lyapunov-exponents. Routes to chaos. Stable and unstable manifolds, natural invariant measure. Symbolic dynamics. Kolmogorov-Sinai entropy, the chaos as a source of information, connection with the Lyapunov-exponents. Thermodynamical formalism. Correlation function, power spectrum. Deterministic diffusion. Quantum mechanical properties of classically chaotic systems.

FIZ/3/040 Mesoscopic Systems I.

In this introductory course we summarize the basic physics of mesoscopic systems.

- Two-dimensional electron gas - nanoscale wires and quantum dots
- Electronic transport - Landauer approach
- Scattering matrix and transfer matrix method
- Green's function method (Fisher-Lee relation)
- Resonant tunneling
- Aharonov-Bohm effect
- Weak localizations
- Universal conductance fluctuations

Literature:

S. Datta: Electronic Transport in Mesoscopic Systems, (Cambridge University Press, Cambridge, 1995) C. W. J. Beenakker and H. van Houten in Quantum Transport in Semiconductor Nanostructures, Solid State Physics, Vol. 44, pp. 1-228, edited by H. Ehrenreich and D. Turnbull, (Academic Press, Inc., Boston, 1991)

Y. Imry: Introduction to Mesoscopic Physics, (Oxford University Press, Oxford, England, 1997)

D. K. Ferry and S. M. Goodnick: Transport in Nanostructures, (Cambridge University Press, Cambridge, 1997)

T. Heinzel: Mesoscopic Electronics in Solid State Nanostructures (Wiley-VCH GmbH & Co. KGaA, Weinheim, 2003)

H-J. Stöckmann: Quantum Chaos, An Introduction (Cambridge University Press, Cambridge, 2000)

FIZ/3/041 Trapped atomic systems II.

In this special course we continue the topics started in Trapped Atomic Gases I. The main interest is put on the current experiments performed in ultracold trapped gases. During the course theoretical issues of a few selected experiments are reviewed. Necessary backgrounds: Quantum Mechanics and Statistical Physics. Background on many body physics is beneficial.

- Field theoretical descriptions of weakly interacting particles in external trapping potential.
- A simple finite temperature approximation for the collective excitations: The Popov approximation for bosons.
- Experiments with rotating condensates with vortices.
- Thomas-Fermi approximation for a single vortex. Excitations of a stable single vortex ground state using the hydrodynamical approach. Sum-rule approach.

•Experiments with trapped fermions, observations of different phenomena in the BEC-BCS transition.

•The mean-field description of the BEC-BCS transition: the Leggett model.

Literature:

•Bose-Einstein Condensation in Atomic Gases, Editors: M. Inguscio, S. Stringari and C. E. Wieman, (IOS Press, Amsterdam, 1999) ISBN: 0-9673355-5-8

•F. Dalfovo, S. Giorgini, L. Pitaevskii and S. Stringari: Theory of Bose-Einstein condensation in trapped gases, Rev. Mod. Phys. 71, 463-512 (1999).

•Qijin Chen, Jelena Stajic, Shina Tan, Kathryn Levin: BCS-BEC Crossover: From High Temperature Superconductors to Ultracold Superfluids, Physics Reports 412, 1-88 (2005).

FIZ/3/042 Cooling and trapping of neutral atoms

We will introduce the basics of laser spectroscopy (spontanious emission, Rabi frequence, Bloch equations, quantum noise). We will discuss the effect of radiation pressure on center of mass motion of atoms in semiclassical approximation. We will derive the radiation pressure, gradient force, we will calculate the velocity dependent friction force acting on an atom. We will incorporate the diffusion by quantum noise in a Langevin equation. We will review the notable laser cooling (Doppler cooling, polarization gradient cooling, sideband cooling) and trapping (dipole trap, optical grid, magneto-optical trap) methods.

FIZ/3/044 New experiments in quantum mechanics

- Neutron interferometry
- Ion and atom traps, laser cooling
- Bose-Einstein condensation
- Micromasers
- Atom optics
- Schrödinger cats
- Photon detectors, two-photon interference
- Entanglement, EPR correlations, Bell inequalities
- Vibrating mirrors

FIZ/3/045 Sensory biophysics II: Bioacoustics

1. History of the Hungarion bioacoustics I. Farkas Kempelen (1734 Bratislava – 1804 Vienna).
2. Characteristics of human speech and sound. Helmholtz cavity resonators. The organ of speech. Practical importance of speech analysis. Sound spectra. Opening of the glottis. The tone of sound. Subjective tone pitch.
3. Direct and indirect sounds. Haas effect. Room acoustics. The dynamics, tune and spectrum of speech. Psychophysics of speech understanding. Acoustical characteristics of speech sounds. Biomechanics and bioacoustics of snoring.
4. Human hearing. Effect of noise and sound masking to hearing threshold. Noise, noise pollution, noise protection.
5. Hair cells of the cochlea. The equilibrium organ. The lateral line organ. The muscles of the middel ear.
6. History of the Hungarion bioacoustics II. III. IV. Róbert Bárány (1876 Vienna – 1936 Uppsala). György Békésy (1899 Budapest – 1972 Honolulu). Péter Szőke (1910 Budapest – 1944 Budapest).
7. Hearing and sound emission of birds. Sounds of singing birds. Hearing of owls.
8. The night butterflies and the ultrasound. Hearing and sound emission of bats. Ultrasound localization.
9. Hearing and sound emission of fishes. Hearing and sound emission of frogs.
10. Acoustic communication of bees. Hearing and sound emission of crickets.
11. Bioacoustic-related movie presentations I.
12. Bioacoustic-related movie presentations II.

FIZ/3/047 Application of optical micromanipulation and optical waveguides in biology

Optical micromanipulation is a new technique in modern biophysics with immense potential. Laser tweezers enable the trapping and manipulation of micrometer sized particles without mechanical contact. Using this technique we can investigate the structure, mechanical properties, function, interactions of biological systems from cells to individual biomolecules. Light propagating in optical waveguides with evanescent character is capable of detecting molecule layers of even single mocelule thickness in a label free manner, as well as achieve strongly localized excitation, surface optical trapping: these are key possibilities in the study of biomolecular interactions. The course discusses the physics of the procedures, introduces the experimental systems and characteristic applications.

FIZ/3/048 Dynamical critical phenomenas

Theory: Critical slowing down. Conventional theory. The dynamic scaling hypothesis. Role of symmetries and conservation laws, Goldstone modes. Nonlinear relaxation. Stochastic models of critical dynamics. Dynamical renormalization group theory.

Applications: Liquid-vapor transformation. Isotropic magnets. Isotropic ferro- and antiferromagnetism. Structural transformations. Superfluid transition in $He^{4.}$

FIZ/3/050 Many-body problem II.

The second semester is devoted to superfluid Bose and Fermi systems. The applied techniques include canonical transformation, equation of motion method, perturbation theory.

- Bose-Einstein condensation in interacting systems.
- Bogoliubov theory of the elementary excitations in the Bose gas. Discussion of the Landau spectrum of elementary excitations in superfluid He II.
- Developing the perturbation theory of Bose systems in the presence of a Bose-Einstein condensate. Beliaev equations.
- Hugenholtz-Pines theorem, phonon spectrum.
- Bogoliubov-Hartree approximation at finite temperature.
- Treating two-body collisions by summing up ladder diagrams.
- Elementary excitations in terms of the exact s-wave scattering length.
- Application to Bose gas in traps.
- Cooper instability in the attracting Fermi gas. Pair correlations, elements of the Bardeen-Cooper-Schrieffer theory.
- Determination of normal and anomalous Green's functions by applying the method of equation of motion.
- Energy gap as order parameter: temperature dependence.
- Crossover from BCS to Bose condensation.

Literature:

- E.M. Lifsic and L.P. Pitaevskii: Statistical Physics, Part 2 : Volume 9 (Pergamon, 1980)
- A.L. Fetter and J.D. Walecka: Quantum Theory of Many-Particle Systems (McGraw-Hill, 1971)
- L.P. Pitaevskii and S. Stringari: Bose-Einstein Condensation (Clarendon Press, 2003)

FIZ/3/051 Fundamentals of the Physics of Solids II

In this lecture we discuss some consequences of the electron-electron interaction in metals.

Main topics: Cohesive energy of the electron systems, Hartree-Fock approximation, exchange potential, correlation energy, Wigner crystal. Electronic response to external perturbations, dielectric function, RPA approximations, screening, Friedel oscillations, Kubo formula. Excitation in the interacting electron gas, quasiparticles and collective excitations, excitons.Landau Fermi liquid theory. Electronic phases with broken symmetry, spin-density waves, charge-density waves, superconducting state. Strongly correlated systems. The Hubbard model, magnetic order, ferro- and antiferromagnetism, metal-insulator transition.

FIZ/3/053 Theory of quantum phenomena
Density matrix, Wigner function, path integral etc. Entanglement, decoherence, master equations, quantum Langevin equations. The zoo of collapse theories. Aharonov-Bohm effect and Berry phases. The strange dynamics of tunneling. A short introduction to quantum information theory.

FIZ/3/054 Universality classes in non-equilibrium systems
Introduction to the dynamic scaling and classifying non-equilibrium universality classes

1. Introduction, dynamic scaling, critical exponents, field-theory formalism, renormalisation, topological phase diagrams, physical aging, scale invariance, transition to chaotic state
2. Dynamic expansion of basic critical statistical systems, domain growing, unsettled states.
3. Non-equilibrium universalities in settled fluctuating systems, systems driven by currents and fields
4. Basic non-equilibrium universality classes in absorbing transitions
5. Dynamic scaling in first order transitions
6. Non-equilibrium universalities in multi component systems, topological effects in low dimensions
7. Non-equilibrium surface-growth classes.

FIZ/3/055 Systems biology: quantitative analysis of intracellular signal transduction networks
To understand how cells work as a complex system is a great challenge of contemporary scientific research. The interdisciplinary attempts involve methods from Molecular Biology, Statistics, Engineering or Physics. By sampling recent research papers, the course introduces widely used quantitative methods of analysis. The topics covered include:

- genetic and molecular oscillators
- cell cycle dynamics
- stochastic reaction kinetics
- bacterial chemotaxis, as an adaptive feed-back system.
- the MAPK signal transduction pathway: a molecular switch
- integrating different scales of organization (molecular, cell, population): lac operon and EGF signaling

FIZ/3/056 Quantitative models of mechanisms in developmental biology
The development of biological shape and function is a long-standing scientific problem. We know that the spactial structure of an organism isn't encoded in its genetic material like in a construction plan – shape and function are created through the interaction between cells and the extracellular matrix. The integration of processes on various (molecular, cell, and tissue) levels is often impossible without using a quantitative analysis. The goal of the course is to teach new concepts and actively used quantitative methods by introducing the latest scientific results in:

- cell motion as biophysics controlled by signal transmission
- cell adhesion, cell sorting
- cell – extracellular matrix (ECM) connections
- morfogenetic forces, tissue mechanics
- gene regulation networks: cis and trans regulation
- segmentation in the embrio: diffusion, waves and clocks
- embrionyc vascular network formation: vasculogenesis and angiogenesis

FIZ/3/059 Evolutionary game theory
This course gives a general introduction to the multi-agent evolutionary game theory based on statistical physics knowledge from the Physics BSc course. The series of lectures includes the following topics: Concepts of classical game theory (strategy, utility, matrix game, Nash equilibrium, etc.); Decomposition of

games; Potential games; Evolutionary rules; Population game theory; Evolutionary games on lattices and graphs. We analyze several interesting phenomena based on the Prisoner's Dilemma and Rock-Paper-Scissors games supposing different connections between the participants.
Literature:
Nowak: Evolutionary Dynamics (Harvard Univ. Press, 2006)
Sigmund: The Calculus of Selfishness (Princeton Univ. Press, 2010)
Szabó and Fáth: Evolutionary games on graphs, Phys. Rep. 446 (2007) 97-216.
Szabó and Borsos: Evolutionary potential games on lattices, Phys. Rep. 624 (2016) 1-60.

FIZ/3/060 Quantum information theory

The quantum information has become an important field of theorethical physics, mathematics, information technology and it is an ever present driving force for quantumtechnological developments. Present lectures are focused on theorethical physical aspects, not the mathematical, IT or engineering viewpoints. The course starts with the summery of theorethical basics of classical and quantum physics, preparing for some of the topics of quantuminformation theory (e.g. private key generation, teleportation, quantum entropies, quantum computer). Lectures notes are available in English: Springer Lecture Notes in Physics 713 (2007).

FIZ/3/061 Quantum information with quantum optics
Quantum optical description of light, modes.Quantum optics of one mode: Fock basis, step operators, coherent states, thermal state, squeezed vacuum in 1 and 2 modes. Beam splitter, passive, linear N ports. The concept of the qubit, 1 qubit operations, CNOT. Entanglement, quantum dense coding, teleportation, no-cloning theorem. Non-classical sources, photon detectors, homodyne detection. The principle of the non-linear and the linear optics quantum computer. Quantum walk and its optical realization, search algorithm via quantum walks. The principles of quantum cryptography and a realization with photons.

FIZ/3/062 Superconductivity
In this lecture we discuss the different phenomenological descriptions and the microscopic theory of the superconductivity. Main topics: Ginzburg-Landau theory, the order parameter, G-L equations, type I and type II superconductors, vortices, critical fields. The Bogoljubov-deGennes equations, mean field approximation, gauge symmetry breaking, Josephson effect. BCS theory of superconductors,pair formation, BCS Hamiltonian and the BCS Ground state, excited states of the superconductors. Strong coupling theory of the superconductivity, Eliashberg equations, retardation effects, tunneling, Andreev scattering. Overview of high Tc superconductors

FIZ/3/063 Graphs in bioinformatics
The lecture gives a general introduction to the theory of complex networks, with special emphasis on biological applications, based on the statistical physics knowledge acquired on Physics B.Sc. The following topics are discussed: basic concepts of networks (adjacency matrix, degree distribution, clustering etc.); Graph models (Erdős-Rényi model, Barabási-Albert model, further scale free models); correlations in networks, assortative and disassortative networks, randomization of networks, modeling of epidemics, immunization of networks, statistics of motifs and groups in biological and social networks.

FIZ/3/064 Clustering with networks

The lecture builds to the statistical physics course of the Physics BSC and gives an introduction to the clustering of the networks. The lecture is based on the following topics: Classical methods (Kerninghan-Lin algorithm, spectral bisection, Fiedler vector, hiearchic clustering, etc.); The Girvan-Newman algorithm and its variations (modularity, edge clustering, coefficient, etc.); Dinamic methods (super paramagnetic clustering, Potts-model based clustering); Methods with local and variable resolution (k-core, clic-percolation method, Fortunato approach, etc.)

FIZ/3/065 Synchrotron radiation and applications

The course presents the basics of synchrotrons and free electron lasers (FEL), the main types and specificities of the produced radiation in the X-ray, extreme UV, and IR ranges, and also its applications - in particular for structural studies in biology, pharmacology, and material sciences; large devices producing neutron beams and their applications will also be reviewed. The following areas will be discussed: physical basics of the interaction between radiation and matter; X-ray absorption spectroscopy (EXAFS and XANES) - enzyme structure and function, X-ray and neutron diffraction - crystal structure of macromolecules (and their super-complexes), quasi-crystals; small angle diffraction (SAXS, SANS) - membrane structures, ultra structure if protein aggregates, liquid crystal structures; reflectometry - mono and multi-layers; elastic and inelastic neutron scattering - structural dynamics of membranes and macromolecules; X-ray microscopy and micro-spectroscopy; far UV circular dichroism and other optical-spectroscopic applications.

FIZ/3/066 Theories of open quantum systems

Classical phenomenas, methods

- Diffusion vs stochastic trajectory equations
- Brownian motion: Fokker-Planck vs Langevin equation
- Microscopic derivations: just conceptions
- Master vs Ito equation, Monte-Carlo method
- Monitoring of noisy systems

Quantum phenomenas, methods

- Depolariation master vs q-trajectory equation
- Spontaneous decay master vs q-trajectory equation
- Q-Brown movement master vs q-trajectory equation
- Q-optical and/or Q-dot master equation
- Microscopic derivations
- Lindblad master vs q-trajectories, MC method
- Monitoring a Q system

FIZ/3/068 Green's functions in nanophysics

The aim of the course is to introduce techniques based on Green's functions to investigate transport phenomena on the nanoscale. The methods are than applied to a wide range of systems from simple tight-binding models to density functional theory based realistic systems.

FIZ/3/069 Chaotic mechanics II

Basic properties of transient chaos.The saddle set and its manifolds.The Kantz–Grassberger formula. Crisis situations, periodic windows. Fractal basin boundaries, uncertainity exponent.Chaotic scattering.Application of chaos: the three body problem, the assymmetric gyroscope, climate change, spreading of contaminants. Numerical determination of chaos parameters.

FIZ/3/070 Quantum electrodynamics in resonator

We will introduce the non-relativistic theory of light and atoms and define the electric dipole approxiamtion of atoms. Discussion of spontanious emisson in Markov approximation. Dipol-dipol interaction. Effect of boundary conditions: Casimir-Polder and van der Waals forces. The basic theory of QED in resonator: the Jaynes-Cummings model. Description of loss processes of resonators. General theory of open quantum systems, density operator and quantum Master equation. Many-particle systems, Dicke model. Semiclassical theory: Maxwell-Bloch equations. Optical bistability. Theory of continously operating, one-mode laser. Bose-Einstein condensate of atoms in optical resonator.

FIZ/3/071 Molecular and biophysical mechanisms of cell motion

During the embryonic evolution, the cell motion is the key to maintain the the normal tissue functions and in the formation of many chronic lesions. The motion of the cells is based on a complex molecular process, which is based on the polymerization and controlled disintegration of proteins and the limitation of the activity of molecular engines. The coordination of the biochemcial processes are done by a network of signal transmitting proteins. Thus the cells are physical entities its deformation are determined by mechanical strains and the micromechanical parameters of their structure. The aim of the lecture is to show how these complicated mechanisms are understood using novel interdisciplinary results. Topics: cell motion during the embryonic evolution, experimental examination of cell motion in two and three dimensional cultures, molecular examination of cell motion and the effect of positive and negative feedbacks in the formation of cell polarization, mechanical forces exerted by cells and the environment of cells (ECM), biophysical model of cell motion, collective cell motions

FIZ/3/073 Group theory in solid state research

Introduction: point groups, fundamental theorems on finite groups, representations, character tables. Optical spectroscopy: selection rules, direct product representations, factor group. Electronic transitions: crystal field theory, SO(3) and SU(2) groups, correlation diagrams, crystal double groups. Symmetry of crystals: space groups, International Tables of Crystallography. Electronic states in solids: representations of space groups, compatibility rules

FIZ/3/074 Introduction to superconductivity

Phenomenology of superconductors. Meissner effect, London equations,electrodynamics of superconductors. Bardeen-Cooper.Schriffer theory: ground state, thermodynamic and transport properties. Ginzburg-Landau theory: free energy, GL equations and their solution, Abrikosov vortices, magnetic properties of Type II superconductors. Josephson effect and its applications. High-temperature superconductivity.

FIZ/3/075 Extremes, Records, and Order-Statistics in Nature

The course is about the statistics of rare events. Historically, the interest was due to engineering applications (e.g. failure of a bridge), but by now, the extreme value statistics and its derivatives such as order statistics and record statistics have found widespread use in various scientific disciplines. The course starts with exposing the basic principles and results using ensembles of independent, identically distributed variables, but the weakly correlated, and the largely unsolved problem of strongly correlated variables will also be discussed. The theory will be employed partly for understanding physical problems (e.g. extreme fluctuations in growth models, ground-state energy fluctuations in spin glasses), and partly for answering more exotic questions (e.g. do the records in maximum temperatures show the global warming?).

FIZ/3/076 Entanglement in quantum many-body systems

In the last decade it became clear that entanglement plays a crucial role in understanding the low-temperature physics of quantum many-body systems. Entanglement carries essential information about the ground states of quantum systems and the study of entanglement properties has become an indispensable tool of modern many-body physics research. In particular, the characterization of universality behind quantum critical phenomena has become unprecedentedly simple with the help of entanglement. It also plays an essential role in understanding the efficiency of modern numerical techniques, such as density matrix renormalization group method. The aim of the course is to give an overview about the essential results of this particular field. We start by introducing the basic concepts (e.g. reduced density matrix, entanglement entropy) as well as the main methods used to determine them. Focus will be given on exactly solvable lattice systems, where many different tools are available to extract the main quantities of interest. Apart from the detailed study of analytical methods, we will give an outlook on the basics of the most important numerical techniques.

FIZ/3/077 Imaging techniques in modern biology

- X-ray computed tomography (CT)
- Magnetic resonance imaging (MRI) and functional magnetic resonance imaging (fMRI)
- Positron emission tomography (PET)
- Ultrasonography
- Tomography with optical microscopes

FIZ/3/078 Fronts and Patterns

The course addresses the theory of pattern formation with attention paid to the fronts related to emerging patterns. The outline is as follows. 1. Historical introduction to pattern formation (why is there something instead of nothing; deterministic and probabilistic descriptions; universal aspects; Bénard instability and the visual hallucinations). 2. Local and global approaches, the use of macroscopic equations, stability properties. 3. Linear stability (fix points, stability matrix). 4. Soft- and hard mode instabilities, emergence of spatial- and temporary structures (e.g. Lotka-Volterra egyenletek, Brusselator). 5. Critical slowing down and the amplitude equations of the slow modes. 6. Secondary instabilities of spatial patterns, complex Landau-Ginzburg equation, space-time chaos. 7. Emergence of structures in the wake of moving fronts (crystal growth, diffusion limited aggregation, patterns in the wake of reaction fronts). 8. Classification of fronts: pushed and pulled fronts. 9. Velocity selection of fronts (e.g. in the Fisher-Kolmogorov-Piskunov equation). 10. Wavelength selection in the wake of fronts (e.g. in the Cahn-Hilliard equation). 11. Patterns in the wake of diffusive fronts (Liesegang phenomena).

FIZ/3/079 Stochastic processes

The course is about the description ot the dynamics of phenomena containing random elements. The outline is as follows. 1. Historical introduction about the probabilistic aspects of statistical physics and of quantum mechanics. 2. Einstein's ideas about the random dynamics of Brownian motion and the steps leading from the Chapman-Kolmogorov equation to the Fokker-Planck equation. 3. Langevin's approach to the Brownian motion and elements of a stochastic differential equation. 4. Probabilistic dynamics in a space of discrete states and the general properties of the Master equation. 5. Stationary state, relaxation to equilibrium, detailed balance, and the conditions the transitions should satisfy. 6. Birth-death type problems and generator-function formalism. 7. Simulation problems (kinetic Ising models). 8. Master equation approach to growing networks. 9. Langevin equation of overdamped oscillator, condition of equilibrium. 10. Current and voltage fluctuations, calculation of time-correlations. 11. Phase transitions and field-theoretic problems: Langevin equation with Gaussian noise and with various conservation laws.

FIZ/3/080 Simulating complex systems

This course gives a hands-on experience to various complex systems. With their own choice of programming environment and tools students simulate various systems, make numerical experiments, demonstrate theoretical results via simulations and investigate phenomena which cannot be handled analytically. The results of these mini-studies are written up in lab reports in similar format to scientific papers. The topics are: Erdos-Renyi graphs, small-world networks, scale-free networks, degree distribution, percolation threshold, spectrum of graphs, Wigner semi-circle law, robustness against attacks, clique finding algorithms. Chaotic maps, dynamical chaos, dimension of attractors. Cellular automata. Neural network simulation and application for machine learning tasks.

FIZ/3/081 Computational modeling

The goal of the course is to introduce the students some of the state of art physics simulation codes which are actively used in various fields of research. The topics are continuously updated to follow the latest trends and developments of computer simulations. The students first learn the background of the given topic, read the related scientific papers, install and boot up the programs. This usually involves the usage of several software libraries (LAPACK, FFTW) and learning basic techniques of distributed and parallel programming (MPI, GPU). Now the GADGET gravitational N-body code, the OpenFOAM hydrodynamics simulation framework and the HOOMD-blue molecular dynamics package are used. After learning the background and installing the programs the students simulate various physical systems and write detailed reports in the style of scientific papers.

FIZ/3/082 Preclinical models in cancer research

The main scope of the course to introduce the most important in vitro and in vivo preclinical models for cancer research with a special emphasis on the approaches that require biophysical methods:

- complex 3D in vitro model systems with cell-cell and cell-matrix interactions as well as with interacting tumor and stromal cells; the state-of-the-art microscopy techniques and image-analysis/data-processing methods; in vivo models of radiotherapy

- in vivo mice models for cancer research (a) orthotopic grafts of human or murine tumor cells and (b) genetically engineered mice models (GEM); in vivo imaging of tumor formation and progression (invasion, metastasis and angiogenesis) (bioluminescence, CT, MR, PET, US, SPECT and their combination)

- predictive preclinical investigation of molecularly targeted, immunomodulatory and radiochemotherapeutic modalities

FIZ/3/083 Python programming and networks

This course is an updated version of a previous course [1] on Perl programming and networks. It aims to help students reach the level where they can routinely apply and combine two major tool sets of current quantitative research: Python and Networks. Currently, Python is a major programming language (i) in physics from the microscopic to the largest length scales, (ii) in computational biology, (iii) in large-scale social and technological networks, and other fields. Networks provide quantitative tools for analyzing many-particle interacting systems and complex data. They are intuitive and can be efficiently connected to linear algebraic, stochastic and other methods. Python will be taught through examples from "Learning Python" [2], "Learn Python the Hard Way" [3], and the problems used in the previous version of the course [1]. Networks will be taught with the "Network Science Book" [4].

References:

[1] The previous version of this course is at http://hal.elte.hu/fij/perl
[2] M Lutz: Learning Python. O'Reilly Media 2013. https://en.wikipedia.org/wiki/Learning_Python
[3] Z A Shaw: Learn Python the Hard Way, http://learnpythonthehardway.org/book
[4] A-L Barabási: Network Science Book, http://barabasi.com/networksciencebook

FIZ/3/084 Data mining and machine learning

The purpose of the course is to give a theoretical and practical knowledge of techniques from the field of modern data mining and machine learning that are applicable at any quantitative field's science. The primary focus of the course is empirical methods of data driven research, hence it complements knowdledge on model-based physics.

FIZ/3/085 Data exploration and visualization

The aim of the course is that students gain practical skills to access large databases/datasets, to handle data stored in different formats, to explore/distill these data and present/visualiz the gathered information. During the course students will come across databases of multiple disciples. Completing of the several projects allows students to gain experience on this field that will be a firm a foundation for later courses on theoretical datamining and advanced computing laboratories.

FIZ/3/086 Data Models and Databases in Science

The purpose of the course is to introduce students to fundamental of data handling, data models and indexing methods in data intensive research. During computer labs strongly tied to the theoretical topics, students solve problems using real data from various fields of science. Taking the course does not require prior knowledge on advanced informatics but demands basic experience on programming and data visualization which can be acquired by taking the class “Data exploration and visualization”.

FIZ/3/087 Data science computer lab

The goal of the course is instil practical skills needed for exploratory data analysis. With the acquired knowledge the student shall be able to perform independent research requiring handling of big data. To this end the students will have to explore a couple of longer running projects inspired data intensive problems drawn from multiple fields such as astronomy, genomics and social networks. The students will familiarize themselves with a wide skillset from various software engineering techniques to presenting their well distilled research in a manner that is accessible for the general public.

FIZ/3/088 Advanced statistics and modelling

The course is aimed to provide an advanced theoretical and practical background that goes beyond the probability theory and statistics knowledge acquirable in the undergraduate physics program. The introduced topics are unavoidable for the efficient evaluation of modern experimental and simulation data, as well as for the analysis of data using computer models and machine learning. The course also gives an outlook into the deterministic and stochastic modelling of chaotic and discrete time processes. By visiting the lectures, student get acquainted with building complex hypotheses and statistical models and the practical methods of evaluation thereof.

FIZ/3/089 Deep learning and machine learning in natural sciences

In this introductory deep learning class students will learn about neural networks, objectives, optimization algorithms and different architectures. During the semester students will work on multiple projects: 2-3 mini project, where students try out different algorithms and architectures, and a more complex final project. In the projects the focus will be on scientific applications of deep learning, for example application in drug discovery, weather prediction and astronomy. To successfully complete the class, prior knowledge in python and numpy (or the willing to learn it fast from handed out materials) is required. In course of the class students will learn about and will get comfortable with popular deep learning frameworks, such as TensorFlow and Keras.

FIZ/3/090 Scientific modelling computer lab

The course is aimed to provide advanced theoretical and practical competences for proactive scientific modeling and project management. Students work on small projects individually and on a large projects throughout the semester in groups. The projects aim computer simulations and models for solving actual problems in various disciplines and scientific fields. By working on the projects and discussing issues in class, students get acquainted with problem setting, with abstracting down to simple models and with suitable programming skills. The projects end with a presentation, where students learn disseminate results and conclude a project.

FIZ/3/091 Computional Studies of Electron Systems

Subject goals

The goal of the course is to give an introduction to the numerical quantitative methods of modern solid state physics. During the course the student will get acquainted with the basics of density functional theory and will be introduced through some practical examples to the codes currently widely used in the community.

Subject description:

- DFT theory: Hohenberg–Kohn theorems, and Kohn–Sham equations
- Basis definition, planewave, local basis set, KKR
- Codes: VASP, SIESTA, quantumespresso
- Derived quantities and forcetheorems: phonons and magnetic properties
- Beyond DFT and strong correlations: LDA+U,DMFT,QMC

Reference: Richard M. Martin: Electronic Structure: Basic Theory and Practical Methods

Program IV: Physics Education

Head of the program: Dr. Tamás Tél

Courses (all optional classroom courses for 5 credits, cannot be repeated, credits to be obtained: 80)

Course desccriptons are not given, this program is available in Hungarian only.

FIZ/T/001 Physics education I

FIZ/T/009 Physics education II (Classical physics, electromagnetism, optics)

FIZ/T/010 Physics education III (Modern physics: atomic physics, molecular and nuclear physics)

FIZ/T/011 Physics education IV (Modern physics: statistical physics, relativity, material science, nonlinear phenomena)

FIZ/T/013 Hystorically relevant experiments of Physics

FIZ/T/002 Foundation of the theory of relativity

FIZ/T/024 Plausible quantum theory

FIZ/T/007 Physics of elementary particles

FIZ/T/016 Energetics and environment

FIZ/T/003 Physics of environmental flows

FIZ/T/005 Chaotic mechanics

FIZ/T/006 Versatile use of computers in pyhsics education

FIZ/T/020 Cooperative phenomena, interdisciplinary aspects

FIZ/T/021 Physics in biology

FIZ/T/022 Physics in chemistry

FIZ/T/022 Recent results in astronomy and space science

Research modul (credits to be acquired: 192 in Programs I-III, 172 in Program IV)

FIZ/K18 Guided research work (in semesters: 1, 2, 3, 4)

18 credits/semester in Programs I-III,

4, 16, 16, 16, credits/semester in Program IV

FIZ/K30 Guided research work (in semesters: 5, 6, 7, 8)

30 credits/semester in all Programs

List of compex examination topics

In Programs I-III one can choose the *main topics* from the following list: Astoromy, Biophysics, Physics of fields and the theory of relativity, Material science, Quantum mechanics, Atomic and molecular physics, Nuclear physics, Optics, Particle Physics, Statistical physics, Solid state physics, Network theory.

In Program IV the main topics should be Physics education.

Secondary topics in Programs I-III (all optional): Solar Physics, Physics of the Solar System,Celestial mechanics, Stellar astronomy, Physics of interstellar matter, Extragalactic astronomy, Cosmology, High energy physics, Physics of exoplanets and exoplanet systems, Data processing and informatics, Molecular biophysics, Bioinformatics, Methods of physics in biology, Evolution theory, Environmental physics, Electromagnetism, Mathematical foundations of relativistic quantum theory, Renormalization and the renormalization group, Generalizations and experimental consequences of the Standard Model, Optical and particle spectroscopy, Plasma physics, Heavy ion physics, Reactor physics and radiation protection, Applications of nuclear methods, Instruments of classical optics, Theory of relativity, Quantum optics and lasers, Phenomena of relativistic quantum electrodynamics and their theory, Low energy hadron physics and nonperturbative quantum chromodynamics, High energy physics and perturbative quantum chromodynamics, Phenomena and theory of electroweak interaction, Experimental methods and data processing in particle physics, Chaotic systems, Growth phenomena and pattern formation, Phase transitions and critical phenomena, Computational methods in statistical physics, Hydrodynamics, Defects in metals and insulators, Mechanical properties of solids, Experimetal methods in solid state research and material science, Liquid crystals, Magnetic properties of condensed matter, Optical properties of condensed matter, Many-body problem, Mesoscopic electron systems, Carbon nanostructures, Computational methods in material science and solid state physics, Physics of amorf materials and nanostructures, Physics of membranes and macromolecules.

Secondary topics in Programs IV can be chosen by merging two topics of the following list: Hystorically relevant experiments of Physics ,Foundation of the theory of relativity Plausible quantum theory, Physics of elementary particles, Energetics and environment, Physics of environmental flows, Chaotic mechanics, Versatile use of computers in pyhsics education,Cooperative phenomena, interdisciplinary aspects, Physics in biology, Physics in chemistry, Recent results in astronomy and space science

Evaluation and control

Fulfilment of the requirements of a given course is evaluated and recorded in the transcript by the lecturer on a five-point scale (1-2-3-4-5, 1: failed .. 5: excellent). Research activities are evaluated and recorded in the transcript by the supervisor on a three-point scale (excellent – acceptable – failed). Credits are approved by the program directors.

Outstanding research achievements, proved by scientific publications, books or books chapters, can be honored by a maximum of 60 ECTS credits. A request for such credits should be submitted by the student and approved by the Council of the PhD School.