SUBJECT GROUPS OF THE TRAINING PROGRAM OF THE DOCTORAL SCHOOL OF PHYSICAL SCIENCES AND THE SYLLABI OF THE COURSES

Solid State Physics subject group

Modern Solid State Physics (2/2/0/e/7)
Theory of Magnetism (2/1/0/e/5)
Theory of Magnetism II (2/0/0/e/3)
Interacting Spin Systems in Real Materials (2/0/0/3)
Group Theory in Solid State Research (2/0/0/e/3)
Superconductivity (2/0/0/e/3)
Semiconductor Physics (2/0/0/e/3)
Magnetic Resonance (2/1/0/e/5)
Optical Spectroscopy in Materials Science (3/0/0/e/5)
Electronic Structure of Solid Matter (2/1/0/e/5)
Topological Insulators (2/0/0/e/3)

Nanophysics/Nanotechnology subject group

Fundamentals of Nanophysics (3/0/0/e/5)
Nanotechnology and Materials Science (3/0/0/e/5)
Transport in Complex Nanostructures (2/0/0/e/3)
Theoretical Nanophysics (2/1/0/e/5)
Advanced Semiconductor Devices (2/0/0/e/3)
Computational Simulation at Atomic Scale in Solids (1/0/1/c/3)
Chemistry in Nanotechnology (2/0/0/e/3)
Nanotechnology Laboratory (0/0/3/c/4)
Trends in Nanotechnology (2/0/0/c/2)
Quantum Computing Architectures (2/0/0/e/3)

Physics of Quantum Systems subject group

Statistical Physics 2 (2/1/0/e/5)
Many-Body Physics (3/1/0/e/6)
Many-Body Physics 2 (2/1/0/e/4)
Particle Physics (2/1/0/e/5)
Quantum Field Theory (3/2/0/e/7)
The Physics of One-Dimensional Systems (2/0/0/e/3)
Statistical Field Theory (2/1/0/e/4)
Advanced Quantum Field Theory (2/1/0/e/4)
Random Matrix Theory and Its Physical Applications (2/0/0/e/3)
Quantum Optics (2/1/0/e/3)
Quantum Entanglement (2/0/0/e/3)
Coherent Controll of Quantum Systems (2/0/0/e/3)

Statistical Physics subject group

Statistical Physics 2 (2/1/0/e/5)
Phase Transitions and Criticality (2/1/0/e/5)
Disordered systems (2/1/0/e/5)
Statistical field theory (2/0/0/e/3)

Dynamical systems (3/1/0/e/5)
Evolutionary Game Theory (2/0/0/e/3)
Complex Networks (2/0/0/e/3)
Artificial intelligence in data science (1/2/0/e/5)

Optics subject group

Physical Optics (2/1/0/e/5)
Laser Physics (2/0/0/e/3)
Optoelectronic Devices (2/0/0/e/3)
Optical Materials and Technologies (2/0/0/e/3)
Optical information Processing and Data Storage (2/0/0/e/3)
Optical Metrology (2/0/0/e/3)
Fundamentals of Optical Design (2/2/0/e/4)
Light sources (2/0/0/e/3)
ELI Preparatory Laboratory (0/0/4/c/4)
Design and Construction of Laser Systems (2/0/0/f/3)
Infrared and Raman Spectroscopy (2/2/0/e/6)
Fundamentals of Photonics (2/1/0/e/5)
Quantum Optics (2/1/0/e/5)
Industrial and Biological Applications of Lasers (2/0/0/e/3)
Fundaments and Applications of Nonlinear Optics (2/0/0/e/3)

Materials Science subject group

Electron- and Ionoptics (2/0/0/e/3)
Electrical and Optical Properties of Solids (2/0/0/e/3)
Vacuum Physics and Technology (2/0/0/e/3)
Material Science Laboratory (0/0/3/c/4)
Fundamentals of Surface Physics (2/0/0/c/3)
Surface Physics and Thin Films (2/0/0/f/3)
Basic materials science and its applications (2/0/0/e/3)
Physical materials science (2/0/0/c/3)
Micro- and nanotechnologies (2/0/0/c/3)
Trends in materials science (1/0/0/e/2)
Spectroscopy and Structure of Matter (2/0/0/e/3)

Nuclear Techniques subject group

Basics of atomic energetics (3/2/0/c/5)
Nuclear Power Plants (3/1/0/e/5)
Material Testing in Nuclear Power Plants (2/0/0/e/3)
Chemistry in Nuclear Power Plants (2/1/0/c/4)
Nuclear power plant operation (2/2/0/c/5)
Radioanalytics (3/0/2/c/6)
Nuclear fuel cycle (2/1/0/c/4)
Nuclear Non-Proliferation (2/0/0/e/3)
Nuclear Energetics and Sustainable Development (2/0/0/c/3)
Introduction to Fusion Plasma Physics (2/0/0/e/2)
Fusion devices (2/0/0/e/3)
Collisional transport in magnetized plasma (1/2/0/c/4)
Instrumentation and control of nuclear reactors (2/1/0/e/4)
Health physics II (2/0/2/e/5)

Neutron and gamma transport calculation techniques (2/1/0/c/4)
Nuclear power plant simulation exercises (0/0/2/c/3)
Migration of radioactive species in environmental and biological matter (2/1/0/e/3)
Safety of radioactive wastes (1/0/1/e/2)
Physics of Nuclear Reactors (3/1/0/e/5)

Medical Physics subject group

Radiobiology (2/1/0/e/4)
Physics of Radiotherapy (2/0/2/e/5)
Radiation therapy II (2/0/0/e/3)
Brachytherapy (2/0/0/e/3)
Quality Assurance and Legislation Issues (2/0/1/e/4)
Radiation Protection in Medical Physics (3/0/1/e/5)
Magnetic resonance and its clinical applications (2/0/0/e/3)
Nuclear medicine (2/0/1/e/4)
Medical imaging (3/1/0/e/4)
Physical foundations of X-ray diagnostics (2/1/0/e/4)

SYLLABI OF THE COURSES

Solid State Physics subject group

Modern Solid State Physics (3/2/0/e/7)
Responsible lecturer: Virosztek Attila

This course describes the behavior of interacting many body systems (mainly electron systems) building on solid state physics and statistical physics knowledge gained while earning a BSC degree in Physics. The following topics are discussed: identical particles, second quantization, interacting electron systems in Bloch and Wannier representation, itinerant ferromagnetism, linear response theory, susceptibility of metals, spin density waves, Bose liquid.

Literature: L. D. Landau and E. M. Lifshitz: Theoretical Physics III., Nonrelativistic quantummechanics (1978), A. A. Abrikosov, L. P. Gorkov and I. E. Dzyaloshinski: Methods of quantum field theory in statistical physics (Dover, New York, 1975), Sólyom Jenő: Fundamentals of the Physics of Solids III. (2003).

Theory of Magnetism (2/1/0/e/5)
Responsible lecturer: Virosztek Attila

Magnetic phenomena are considered as electron correlation effects. This course builds heavily on knowledge gained by successful completion of the course "Modern solid state physics". The following topics are discussed: Landau levels in magnetic field, magnetism of extended electron states, magnetism of atoms and ions, magnetite, direct exchange, kinetic exchange, Mott transition, Mott insulators, mean field theory of magnetic ordering, the ferromagnetic Heisenberg model, the antiferromegnetic Heisenberg model.

Literature: Patrik Fazekas: Lecture notes on electron correlation and magnetism (World Scientific, Singapore, 1999).

Theory of Magnetism II (2/0/0/e/3)
Responsible lecturer: Virosztek Attila

The basic concepts and results from the first part of the course are assumed to be familiar. The following topics are discussed: spontaneous breaking of symmetry in the Heisenberg model, crystal field theory, symmetries and degeneracies, transition metal atoms in cubic crystal field, further symmetry breakings and symmetries, itinerant ferromagnetism, correlated metals, heavy fermions.

Literature: Patrik Fazekas: Lecture notes on electron correlation and magnetism (World Scientific, Singapore, 1999).

Interacting Spin Systems in Real Materials (2/0/0/e/3)
Responsible lecturer: Penc Karlo

The lecture aims at the understanding of the magnetic properties of various Mott insulators, comparing theoretical understanding with experimental measurements. It builds on the "Theory of magnetism II" course (but it can also be followed on its own). Topics: The origin of spin exchanges in materials. Neutron and optical spectra. Excitations in S=1/2 and S=1 spin chains, AKLT state. Spin ladders in a magnetic field. Spin waves in $LaCu_2O_4$ and other antiferromagnets, comparing calculated spectra with neutron experiments. Magnetization plateaus in $SrCu_2(BO_3)_2$ and in frustrated systems, the role of quantum fluctuations and lattice distortions. Ground state degeneration and magnetic monopoles in spin ice. Nematic and multipolar ordering in frustrated systems. Magnetoelectric coupling in multiferroic materials. Realization of the Kitaev model in two and three-dimensional iridium oxides, the role of strong spin-orbit coupling. Magnetic excitations with finite Chern number.

Literature: selected review articles

Group Theory in Solid State Research (2/0/0/e/3)

Responsible lecturer: Kriza György

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.

Literature: G. Burns, Introduction of Group Theory with Applications, (Academic Press, New York, 1977). Wigner Jenő: Group theoretical method in quantum mechanics (1979).

Superconductivity (2/0/0/e/3)
Responsible lecturer: Kriza György

Phenomenology of superconductors. Meissner effect, London equations, electrodynamics of superconductors. Bardeen-Cooper-Schrieffer 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 superconductors. Prerequisites: *Modern Solid State Physics*.

Literature: Michael Tinkham, Introduction to Superconductivity: Second Edition (Dover Books on Physics, 2004), L. D. Landau – E. M. Lifshitz: Theoretical Physics IX., Statistical physics II. (1981); Sólyom Jenő: Fundamentals of the Physics of Solids III. (2003)

Semiconductor Physics (2/0/0/e/3)
Responsible lecturer: Simon Ferenc

Introduction: importance of semiconductor physics, modern applications, the limitations of electronics. Charge carriers in semiconductors: band structure, envelope function, lattice distortions, impurities, localized states, shallow and deep levels. Band structure of semiconductors: spin-orbit interaction, kp model. Transport phenomena: quasiclassical dynamics, Boltzmann equation, conductivity, Hall-effect, magnetoresistance, thermoelectric and thermomagnetic phenomena. Diffusive phenomena in semiconductors: inhomogeneous semiconductors, diffusion, diffúzió, Einstein-relation, conduction, Gunn-diode, p-n junction, Zener-diode, tunnel diode, bipolar transistors, JFET. Characterization and engineering of semiconductors: traditional and epitaxial growth, characterization techniques, lattice matching, band-engineering, heterostructures, superlattices, highe electron mobility 2DEG and its high frequency applications, fabrication of semiconductor nanostructures. Field effect and its applications: surface density of states, remote doping, Schottky barrier, Schottky diode, ohmic contacts, MOS-structures, High-k dielectrics, flash memories, solar cells, CCD devices, the fundamentals of CMOS technológy. Optical properties of semiconductors: interaction with light, photoconduction, absorpion of free charge carriers, recombination mechanisms, the principles and applications of light emitting diodes and semiconductor lasers.

Literature: Yu and Cardona: Fundamentals of Semiconductors, Springer, 2010, Graduate Texts in Physics Series

Magnetic Resonance (2/1/0/e/5)
Responsible lecturer: Fehér Titusz

The course discusses one of the most important investigation methods in physics, chemistry and medical sciences. It is based on the electrodynamics and quantum mechanics studies required for the BSC degree. Topics include experimental methods of electron and nuclear magnetic resonance, Bloch equations, dipole-dipole interaction, motional narrowing, crystal fields and fine structure, hyperfine splitting, chemical shift, magnetic resonance in metals, superconductors and magnetically ordered materials. The fundamentals of magnetic resonance imaging (MRI)

Literature: C. P. Slichter Principles of Magnetic Resonance (Springer, Berlin, Heidelberg, New York, 1992).

Optical Spectroscopy in Materials Science (3/0/0/e/5)

Responsible lecturer: Bordács Sándor

Electromagnetic waves in vacuum and in a medium; complex dielectric function, interfaces, reflection and transmission. Optical conduction in dipole approximation; linear response theory, Kramers-Kronig relation, sum rules. Simple optical models of metals and insulators; Drude model, Lorentz oscillator. Optical phonons, electron-phonon interaction. Optical spectroscopes: monochromatic- and Fourier transformation spectrometers. Optical spectroscopy of interacting electron systems: excitons, metal-insulator transition, superconductors. Magneto optics: methods and current applications.

Literature:
"Solid State Spectroscopy" H. Kuzmany (Springer, 1998)
"Solid State Physics: Problems and Solutions" L. Mihály and M.C. Martin (Wiley, 1996)
"Magneto-optics", S. Sugano and N. Kojima (Springer, 1999).

Electronic Structure of Solid Matter (2/1/0/e/5)
Responsible lecturer: Szunyogh László

Building on the knowledge in quantum mechanics and solid state physics, this course aims to discuss modern theories and methods for the electronic structure of solid matter. The following topics will be outlined: Foundations of the static density functional theory. Variational and pseudopotential methods. Ab initio methods for correlated systems (LDA+U, self-interaction correction, DMFT). Point-group and time reversal symmetries in the electronic structure. Surface states, the Bychkov-Rashba effect. Alloy theory, the coherent potential approximation. Metallic (itinerant) magnetism, method of the disordered local moments.

Literature: Sólyom Jenő: Fundamentals of the Physics of Solids II. (2003).

Topological Insulators (2/0/0/e/3)
Responsible lecturer: Pályi András

Research in the past decades revealed new features in the electronic band theory of solids. Topological insulators are insulating crystalline materials that support conducting – sometimes perfectly conducting – electronic surface states. In this course, we use simple models to introduce the topological invariants relevant for band theory, provide theoretical tools to calculate them, and demonstrate how topology protects the surface states from perturbations. We also give insight to the general theory of topological insulators, and review experimental setups and results.

Literature: J. K. Asbóth, L. Oroszlány, A. Pályi, A Short Course on Topological Insulators, Springer Lecture Notes in Physics, 919 (2016).

Nanophysics/Nanotechnology subject group

Fundamentals of Nanophysics (3/0/0/e/5)
Responsible lecturer: Halbritter András

The building blocks of nowadays electronic devices have already reached a few tens on nanometers sizes, and further miniaturization requires the introduction of novel technologies. At such small length-scales the coherent behavior and the interaction of electrons, together with the atomic granularity of matter induce several striking phenomena, that are not observed at the macroscopic scale. The course gives an introduction to a broad set of nanoscale phenomena covering the following topics: characteristic length-scales; basic concepts of quantum transport, conductance quantization; coherent and incoherent transport, interference phenomena in nanostructures; mesoscopic phenomena in atomic and molecular nanojunctions; quantized Hall effect; noise phenomena in nanostructures; graphene nanostructures, 2D heterostructures; quantum dots.

Literature:
S. Datta: Electronic Transport in Mesoscopic Systems, Cambridge University Press, 1997.
T. Ihn: Semiconducting nanosctructures, Oxford University Press, 2010.
Y.V. Nazarov, Y.M. Blanter: Quantum Transport: Introduction to Nanoscience, Cambridge University Press, 2009.

Nanotechnology and Materials Science (3/0/0/e/5)
Responsible lecturer: Csonka Szabolcs

This course gives an introduction to the main trends in nanotechnology and material science. We cover advanced fabrication and measurement techniques by giving examples from state-of-the-art research and development results. The course addresses the following topics: Novel concepts and modern material systems in nanotechnology. Advanced imaging methods from electron microscopy to atomic resolution scanning probe techniques. Top-down nanofabrication techniques: photo and electron beam litography, deposition and special patterning techniques. Bottom-up approaches and self-organizing nanostructures. Semiconductor technology and novel concepts in information technologies. Investigation of electronic and vibrational properties by optical spectroscopy. Advanced surface analysis techniques.

Literature:
Douglas Natelson: Nanostructures and Nanotechnology,
Stuart Lindsay: Introduction to Nanoscience,
Springer Handbook of Nanotechnology

Transport in Complex Nanostructures (2/0/0/e/3)
Responsible lecturer: Makk Péter

The course overviews the complex physical phenomena in various hybrid nanostructures with a special emphasis on the following topics of superconductiong nanostructures and spintronics:

Introduction to mesoscopic superconductivity. Andreev reflections, BTK theory and mesoscopic proximity effects. Multiple Andreev Reflections. Advanced applications of the Josephson effect. Investigation of Andreev Bound states and the current-phase relation. Andreev Qubits. Superconducting islands, Andreev states in quantum dots. Majorana fermions.

Basic concepts of spintronics. Magnetization measurements: magnetic force microscopy, scanning NV center methods, X-ray magnetic circular dichroism, etc. Magnetoresistance phenomena (AMR, GMR, TMR). Spin injection, non-local measurements. Semiconductor spintronics, Rashba effect, spin relaxation, weak anti-localization. Spintronics in quantum dots. Optical spin injection, electron spin resonance. Spin Hall phenomena. Exotic spin structures, multi ferroic materials, skyrmions. Antiferromagnetic spintronics. Spin transfer torque, spin pumping

Literature: selected review articles

Theoretical Nanophysics (2/1/0/e/5)
Responsible lecturer: Zaránd Gergely

Nanosystems and mesoscopic systems represent the most intensively studied areas of modern solid-state physics: modern lithographic procedures enable us to create semiconducting devices and metallic grains, where electrons move coherently. Today, we can contact individual grains, atoms and molecules, and place them into micro-resonators. The goal of the course is to cover novel phenomena occurring in such devices. The course covers the following subjects: description of small grains (Coulomb interaction, coherence, single particle levels); fundamentals of random matrix theory (university classes, level repulsion); Coulomb blockade and spectroscopy (master equation, co-tunneling and Kondo effect); conductance and noise of point contacts; molecular transport; superconducting grains, Josephson junctions, and quantum bits; Nanowires, edge states, and hybrid structures. The course is accompanied by a series of problem sets, which the students are supposed to prepare and hand in by the end of the semester.

Literature: Supriyo Datta, Lessons from Nanoscience: A New Perspective on Transport, World Scientific, 2012; E. Akkermans, G. Montambaux, J.-L. Pichard, and J. Zinn-Justin: Mesoscopic Quantum Physics, North Holland, 1996

Advanced Semiconductor Devices (2/0/0/e/3)
Responsible lecturer: Volk János

The course introduces the hardware building blocks of modern information technologies from traditional semiconductor architectures to the the most up-to-date concepts, technologies and devices. Topics: History of semiconductor devices and semiconductor industry. Advanced silicon technologies from crystal growth to micromachining and nanofabrication techniques. Si devices from traditional MOS FETs to trigate transistors or CCD sensors. Memory devices (SRAM, DRAM, flash). Si solar cells. Compound semiconductors, band engineering, two dimensional electron gas systems, quantum wells, light emitting and laser diodes, high electron mobility transistors, GaN technology. Organic semiconductors: polymer solar cells, OLEDs, printed electronics. Perovskite solar cells. Sensors and actuators: MEMS, physical, chemical, biological sensors, actuators, robotic applications, biointerfaces, artificial skin and nose. Novel device platforms: spintronic devices and resistive switching memories. Novel computing architectures: brain inspired computing, in memory computing, hardware implementation of artificial neural networks.

Literature:
Simon M. Sze, Kwok K. Ng: Physics of Semiconductor Devices
Rainer Waser: Nanoelectronics and Information Technology: Advanced Electronic Materials and Novel Devices. Saját jegyzetek / handouts.

Computational Simulation at Atomic Scale in Solids (1/0/1/c/3)
Responsible lecturer: Gali Ádám

The course overviews the atomic-scale simulation methods of solids covering the topics bellow. Introduction, potential applications. Geometry of molecules and perfect solids. Various models of solids. The separation of nuclei and electrons: Born-Oppenheimer approximation, pseudopotentials, projectors. Typical base functions and their characteristics: plane waves, localized bases. Hartree-Fock theory and related methods. Semiempirical computational methods. Density functional theory: Hohenberg-Kohn, Kohn-Sham theorems and their (semi)local approximations. DFT-based tight binding methods. Hybrid functionals. Time dependent density functional theory, many particle perturbation methods. In addition to the the overview of the theoretical principles the students also apply the above methods along the computational lab occasions.

Literature: Gali Ádám: Atomi szintű számítógépes szimuláció szilárdtestekben: elmélet és gyakorlat I.

Chemistry in Nanotechnology (2/0/0/e/3)
Responsible lecturer: Lagzi István László

The course presents recent developments in nanotechnology and nanoscience using chemical methods. We will overview measurement techniques for nanosclae building blocks, namely transmission electron microscopy (TEM), scanning electron microscopy (SEM), dynamic light scattering (DLS). Synthesis of nanoparticles: chemical, physical and biological methods and chemical stabilization of nanoparticles. Purification and size and shape-selective purification of nanoparticles. The stability of nanoparticles and interactions existing at nanoscale and using them for the self-assembly of nanoscopic components: nanostuctured materials. Usage of nanoparticles in chemistry, medicine and chemical robotics. Targeted drug delivery applications.

Literature:
Nanoseparations: strategies for size and/or shape-selective purification of nanoparticles, B Kowalczyk, I Lagzi, BA Grzybowski, Current Opinion in Colloid & Interface Science 16 (2), 135-148
A DNA-based method for rationally assembling nanoparticles into macroscopic materials, CA Mirkin, RL Letsinger, RC Mucic, JJ Storhoff, Nature 382 (6592), 607
Scanometric DNA array detection with nanoparticle probes, TA Taton, CA Mirkin, RL Letsinger, Science 289 (5485), 1757-1760

Nanotechnology Laboratory (0/0/3/c/4)
Responsible lecturer: Krafcsik Olga

This laboratory course provides a practical insight to state-of-the-art nanofabrication, and nanoscale characterization techniques. The students accomplish a technological laboratory process in the framework of miniprojects. All miniprojects consist of two fundamental ingredients: (i) the fabrication of nanostractures (e.g. the production of nanocircuits by electron beam lithography), (ii) the microscopic characterization of the produced nanostructures by advanced methods (e.g. scanning electron microscopy, atomic force microscopy, Raman microscopy, etc.). Relying on the guidance of a chosen tutor, the students prepare an initial project plan, they work independently on the project, and they account on their work in a midterm progress report and in a final project report.

Trends in Nanotechnology (2/0/0/c/2)
Responsible lecturer: Csonka Szabolcs

The courses provides insight to the most up-to-date results and the state of the art measurement and fabrication techniques in the field of nanotechnology. The selected topic (like micro-and nanomechanical systems, scanning probe techniques, nanobiosensors, semiconductor nanostructures, nanoinformatics, etc.) are presented by invited experts of the field.

Quantum Computing Architectures (2/0/0/e/3)
Responsible lecturer: Pályi András

Fundamentals of qubits: dynamics, measurement, operations, circuits, and algorithms. Control of quantum systems: from model Hamiltonians to logical operations. Electron spin–based qubits. Coherent control and readout of electron spin. Mechanisms of information loss in electron spin systems. Introduction to superconductivity and the Josephson effect. Control and readout of superconducting qubits. Mechanisms of information loss in superconducting qubits. Circuit quantum electrodynamics. Entanglement in superconducting qubits. Multi-qubit devices. Overview of current research directions.

Physics of Quantum Systems subject group

Statistical Physics 2 (2/1/0/e/5)
Responsible lecturer: Zaránd Gergely

Critical phenomena: scaling and critical exponents, fundamentals of renormalization group, correlation functions and Ginzburg criterion. Time-dependent correlations: equilibrium correlations, classical fluctuations, Onsager relation. The density operator, Neumann equation, entropy. Kubo formula, fluctuation dissipation theorem. Non-equilibrium dynamics: Brown motion, diffusion, Langevin equation, Fokker Planck equation. Master equation, H theorem, principle of maximal entropy. Detailed balance and Monte Carlo simulations. Simulated annealing. Interacting quantum systems: Superfluidity, Gross-Pitaevskii equation, quantum gases.

Optional subject: High temperature expansion, Fermi liquid theory.

Literature:
Kertész János, Zaránd Gergely, Deák András: Statistical Physics lecture notes; David Chandler: Introduction to Modern Statistical Physics

Many-Body Physics (3/1/0/e/6)
Responsible lecturer: Dóra Balázs

Second quantization, definition of Green's functions and their relations to physical quantities. Heisenberg, Schrödinger and interaction pictures. Perturbation theory, diagrammatics (Wick's theorem, Feynman diagrams), resummations (self energy, vertex function, skeleton diagrams), equation of motion method. The ground state energy of dense, interacting electron gas. Friedel oscillations around a charged impurity. Anderson's orthogonality catastrophe and Fermi edge singularity. RKKY interaction between localized magnetic moments. Mean-field theory of two dimensional antiferromagnets.

Literature:
G.D. Mahan: Many-Particle Physics (Plenum Press, New York and London, 1981); A.A. Abrikosov, L.P. Gorkov and I. Dzialoshinskii: Methods of Quantum Field Theory in Statistical Mechanics (1963)

Many-Body Physics 2 (2/1/0/e/4)
Responsible lecturer: Dóra Balázs

Imaginary time formalism, Matsubara frequencies. Finite temperature Green's functions. Diagrammatic rules, self-energy, Dyson equation. Expressing physical quantities in terms of Green's functions. Lehmann representation, linear response theory. Discussion of the finite temperature interacting electron gas, screening, ring diagrams, interaction correction to the equation of state of an electron gas. Superconductivity at finite temperatures within mean-field theory, normal and anomalous Green's functions. Gap equation and its solution at T=0 and around the transition temperature, density of states, spectral function.

Literature: G.D. Mahan: Many-Particle Physics (Plenum Press, New York and London, 1981); A.A. Abrikosov, L.P. Gorkov and I. Dzialoshinskii: Methods of Quantum Field Theory in Statistical Mechanics (1963)

Particle Physics (2/1/0/e/5)
Responsible lecturer: Takács Gábor

Overview of scales in Nature. Special relativity. Classification of particles. Klein-Gordon and Dirac equations. Introduction to weak interactions. Beta decay, neutrino. Parity and CP violation. CPT symmetry. Introduction to strong interactions. Isospin, strangeness. SU(3) quark model. Relativistic field theory, canonical formalism, Noether theorem. Basic principles of quantum field theory. Feynman rules. Weak interactions: charged currents, FCNC and GIM mechanism. Flavour mixing. Neutrino oscillations. Non-Abelian gauge theories. Fundamentals of quantum chromodynamics. Spontaneous symmetry breaking, Goldstone theorem. Higgs mechanism. Electroweak unification. The Standard Model. The Higgs boson. Overview of latest developments and open problems in particle physics.

Literature: David Griffiths: Introduction to Elementary Particles (Wiley-VCH); electronic lecture notes.

Quantum Field Theory (3/2/0/e/7)
Responsible lecturer: Takács Gábor

Canonical quantisation. Quantised Klein-Gordon and Dirac fields. Spin-statistics theorem. Interacting fields. CPT theorem. Scattering theory and the S-matrix. Unitarity and microcausality. Perturbation theory, Feynman rules for correlation functions. Asymptotic states. Feynman rules for the S matrix. Cross sections and decay rates. Quantisation of the electromagnetic field. Gauge invariance. Kallen-Lehmann representation, sum rules. LSZ reduction formulae. Feynman path integral in Hamiltonian and Lagrangian formalism. Functional formalism.Grassmann variables and path integrals for fermions. Renormalisation theory. Classification of divergences, counter term formalism. Symmetries and Ward identities. Spontaneous symmetry breaking. Renormalisation group, Callan-Symanzik equation. Connection with theory of critical phenomena.

Literature: M.E. Peskin and D.V. Schroeder: An Introduction to Quantum Field Theory (Addison-Wesley); C. Itzykson and J-B. Zuber: Quantum Field Theory (Dover Publications); S. Weinberg: The Quantum Theory of Fields I-III (Cambridge University Press)

The Physics of One-Dimensional Systems (2/0/0/e/3)
Responsible lecturer: Zaránd Gergely

The course introduces students to the physics of one-dimensional interacting electron and spin systems. These systems—where fundamental phenomena such as spin- and charge-density waves, antiferromagnetic correlations, and exotic superconducting states occur—provide an excellent testing ground for solid-state physicists, as highly efficient quantum field-theoretical methods are available in one dimension. At the same time, such one-dimensional systems are often realized in practice, for example in carbon nanotubes, quasi-one-dimensional materials, and in the form of edge states. The course assumes a basic knowledge of Green's function techniques (Many-Body Problem I) and is organized around the following topics: one-dimensional systems in nature and the Hubbard model (instabilities, spin- and charge-density waves, mapping to the Heisenberg model); fundamental properties of spin chains (the Haldane conjecture, spin coherent states, spin liquids, basics of the Bethe Ansatz); continuum descriptions (renormalization group and the Tomonaga–Luttinger model); bosonization (spin–charge separation, the Luttinger liquid phase, bosonization of spin systems); and the role of disorder.

Literature: G.D. Mahan: Many-Particle Physics (Plenum Press, New York and London 1981); John Cardy: Scaling and Renormalization in Statistical Physics (Cambridge University Press 1997); Jan von Delft, Herbert Schoeller: Bosonization for Beginners-Refermionization for Experts, Annalen Phys. 7, 225-305

Statistical Field Theory (2/1/0/e/4)
Responsible lecturer: Takács Gábor

Second order phase transitions. Field theoretic description of the Ising model in d dimensions. Renormalisation group, fixed points, classification of couplings. Landau-Ginsburg description. Wilson's RG in field theory, beta function. Idea of epsilon expansion. Conformal field theory in d dimensions. Conformal symmetry, energy-momentum tensor, scaling fields. Conformal Ward identities. 2 and 3 point functions. Conformal symmetry in 2 dimensions. Primary and quasi-primary fields, Ward identity. Energy-momentum tensor, Ward identity and its relation to the free energy. Virasoro algebra. Operator-state correspondence. Correlators of descendent fields from Ward identities. Highest weight representations. Verma modules. Singular vectors. Minimal models. Operator product expansion in minimal models. Modular invariance and partition functions. Operator product coefficients and conformal bootstrap. Vicinity of critical point. C-theorem. Perturbative RG flows.

Literature: G. Mussardo: Statistical Field Theory (Oxford University Press);C. Itzykson and J-M.

Drouffe: Statistical Field Theory (Cambridge University Press); P. Ginsparg: Applied Conformal Field Theory (arXiv:hep-th/9108028)

Advanced Quantum Field Theory (2/1/0/e/4)
Responsible lecturer: Takács Gábor

This course builds upon the course Quantum Field Theory and discusses advanced topics such as (i) renormalization group and scaling; (ii) role of symmetries and their breaking, (iii) advanced functional techniques, non-perturbative methods and their applications, (iv) effective action, effective potential and (v) instantons and quantum tunneling.

Literature: M.E. Peskin and D.V. Schroeder: An Introduction to Quantum Field Theory (1995, Addison-Wesley); C. Itzykson and J-B. Zuber: Quantum Field Theory (2006, Dover Publications); S. Weinberg: The Quantum Theory of Fields I-III (1995, 1996, 2000, Cambridge University Press)

Random matrix theory and physical applications (2/0/0/e/3)

Responsible lecturer: Varga Imre

Random matrix theory provides an insight of how one can achieve information relatively simply about systems having very complex behavior. The subject based on the knowledge acquired in quantum mechanics and statistical physics together with some knowledge of probability theory provides an overview of random matrix theory. The Dyson ensembles are defined with their numerous characteristics, e.g. the spacing distribution, the two-level correlation function and other quantities derived thereof. Then the thermodynamic model of levels is obtained together with several models of transition problems using level dynamics. Among the physical applications the universality classes are identified in relation to classically integrable and chaotic systems. The problem of decoherence is studied as well. Then the universal conductance fluctuations in quasi-onedimensional disordered conductors are investigated. Other models are investigated: the disorder driven Anderson transition and the random interaction model of quantum dot conductance in the Coulomb-blockade regime. We use random matrix models to investigate chirality in two-dimensional and Dirac systems and the normal-superconductor interface. The remaining time we cover problems that do not belong to strictly physical systems: EEG signal analysis, covariance in the stock share prize fluctuations, mass transport fluctuations, etc.

Literature: M.L. Mehta: Random matrices (Elsevier, 2004); válogatott review cikkek: Th. Guhr, A. Müller-Groeling, H.A. Weidenmüller, Phys. Rep. 299 (1998) 198; C.W.J. Beenakker, Rev. Mod. Phys. 69 (1997) 731; Y. Alhassid, Rev. Mod. Phys. 72 (2000) 895; G. Montambaux, in *Les Houches, LXIII 1995 Quantum Fluctuations,* etc.

Quantum Optics (2/1/0/e/3)
Responsible lecturer: Takács Gábor

The course is an introduction to quantum optics. The topics covered are:

Coherence in classical optics. Radiative transitions in quantum matter, atoms and semiconductors. Photodetection, photon statistics, super- and sub-Poissonian light. Hanbury-Brown and Twiss interferometry, photon antibunching. Coherent and squeezed states, Wigner functions. Resonant light-atom interaction, density states, Rabi oscillation. Atoms in cavities, Purcell effect, strong coupling. Cold atoms, Bose condensation, optical lattices. Quantum cryptography and quantum information. Entanglement, quantum teleportation, Bell inequalities.

Literature: Quantum Optics: an Introduction, Mark Fox, OXFORD MASTER SERIES IN PHYSICS, Oxford University Press 2006

Quantum entanglement (2/0/0/e/3)
Responsible lecturer: Lévay Péter

The aim of this course is the presentation of quantum entanglement on finite dimensional Hilbert spaces that help the understanding of abstract notions. Topics: introduction of the applied information theoretic and convex-geometrical concepts, characteristics of discrete probability distributions, (entropies) and the operations on them (stochastic mapping), the space of states (projective Hilbert space and the space of convex density matrices), characterizing quantum states (entropies) and the operations on them (totally positive mapping), quantum measurements (Shrödinger's cat), compound systems and entanglement, operations (quantum teleportation) classification of entangled states (general arguments, LOCC, SLOCC, 2 and 3 qubit results), entanglement criterions (witness-operators, CHSH-Bell inequalities), entanglement measures (general arguments, 2 and 3 qubit results).

Literature:
I. Bengtsson, K Zyczkowski, Geometry of Quantum States, Cambridge University Press, Cambridge, 2006
M. Nielsen, I Chuang, Quantum Information and Quantum Computation, Cambridge University Press, Cambridge, 2000

Coherent control in quantum systems (2/0/0/e/3)
Responsible lecturer: Kis Zsolt (Varga Imre)

Atomic transitions coupled to electromagnatic field. Two-level systems: Rabi oscillation, analytically solvable models. Coherent controll of atoms with many nondegenerate levels. Robust controll mechanisms: adiabatic population transfer. Application of quantum controll in quantum information theory. Maxwell-Bloch equations. Linear susceptibility. Measurement of T1 and T2 times. Resonant nonlinear optics: electromagnetically induced transparency, coherent photon-memory. Coherent controll of molecular vibrational states.

Literature:
Bruce W. Shore: The Theory of Coherent Atomic Excitation;
Marlan O. Scully and M. Suhail Zubary: Quantum Optics;
William H. Louisell: Quantum Statistical Properties of Radiation;
Claude Cohen-Tannoudji, Jacques Dupont-Roc, Gilbert Grynberg: Atom-Photon Interactions

Statistical Physics subject group

Statistical Physics 2 (2/1/0/e/5)
Responsible lecturer: Zaránd Gergely

Critical phenomena: scaling and critical exponents, fundamentals of renormalization group, correlation functions and Ginzburg criterion. Time-dependent correlations: equilibrium correlations, classical fluctuations, Onsager relation. The density operator, Neumann equation, entropy. Kubo formula, fluctuation dissipation theorem. Non-equilibrium dynamics: Brown motion, diffusion, Langevin equation, Fokker Planck equation. Master equation, H theorem, principle of maximal entropy. Detailed balance and Monte Carlo simulations. Simulated annealing. Interacting quantum systems: Superfluidity, Gross-Pitaevskii equation, quantum gases.

Optional subject: High temperature expansion, Fermi liquid theory.

Literature:
Kertész János, Zaránd Gergely, Deák András: Statistical Physics lecture notes; David Chandler: Introduction to Modern Statistical Physics

Phase Transitions and Criticality (2/1/0/e/5)
Responsible lecturer: Zaránd Gergely

The course gives a small overview of major phase transition problems and critical systems in equilibrium statistical physics, in quantum mechanics and non-equilibrium statistical physics. Subests include: Mean field theory, critical exponents, Ginzburg criterion, Lower critical dimension, Goldstone modes. Hubbard-Stratonovic transformation, continuum theory, Goldstone modes large N limit, The Basics of renormalization: decimation the one dimensional Ising model, higher dimensions and critical point. The two-dimensional Ising case: the generalized transformation, fixed points, critical surface, relevant and irrelevant operators. Critical scaling all the free energy, universal exponents, correlation functions of scaling operators. Finite size scaling Quantum critical systems: discussion of the one-dimensional Ising chain. Quantum classical mapping, higher dimensional phase diagrams. Super fluidity and the XY model. Vortices and Kosterlitz-Thouless phase transition. Surface roughening Family-Vicsek scaling

Literature:
John Cardy: Scaling and Renormalization in Statistical Physics (Cambridge University Press, 1996).
Subir Sachdev, Quantum Phase Transitions, Cambridge University Press (2011).

Disordered systems (2/1/0/e/5)
Responsible lecturer: Zaránd Gergely

Disorder is present everywhere around us, and it leads to fascinating phenomena. This course covers the following topics: Structural disorder: Fractals, liquids, glasses, quasicrystals, amorphous metals, granular materials, Edwards ensemble. Percolation. Disordered magnetic systems: Hysteresis, memory effects, and Preisach model. Domain wall motion: mean field theory, Barkhausen noise. Disordered ferromagnets and Griffith phase. Frustrated spin systems and spin glasses: phyenomenology, Sherrington-Kirpatrick model, TAP equations. Replicas, and replica symmetry breaking. Dropplet theory. Localization theory: Disordered semiconductors and impurity bands. Locaization transition and Anderson's theory. The scaling theory of localization. The Coulomb glass. Crytical wave function and multifractal properties. Quantum Hall effect. Quantum glasses: The Bose glass. Fisher scaling and the strong disorder fixed point.

Literature: B. Kramer, A. MacKinnon review Rep. Prog. Phys. 56, 1469 (1993).

Statistical field theory (2/0/0/e/3)
Responsible lecturer: Takács Gábor

The course is an introduction to applications of relativistic quantumfield theory in statistical systems. Main topics are: Critical phenomena, scaling, scale invariance. Fundamentals of field theoretic description. Scale invariance and conformal symmetry in arbitrary dimensions. Two-dimensional conformal field theories. Virasoro algebra. Operator classification, state-operator correspondence. State space and partition function. Operator algebra. Correlation functions in conformal field theories. Vicinity of critical points. Renormalization group flows. Relevant and irrelevant perturbations. Conserved quantities. Integrable quantum field theories. Analytic S-matrix theory, bootstrap. Form factors and correation functions in integrable quantum field theories. Finite size effects. Thermodynamic Bethe Ansatz and truncated statespace method. Non-integrable models.

Literature Mussardo: Statistical Field Theory, Itzykson-Drouffe: Statistical Field Theory

Dynamical systems (3/1/0/e/5)
Responsible lecturer: Gergely Barnabás

This course deal with the following topics: dynamical systems with continuous and discrete time, Grobman-Hartman lemma, stable-instable-central ensemble, Poincaré normal formulae, attractors, Ljapunov functions, LaSalle principle, phase portrait, Structural stability, bifurcations of equilibrium and fix points, bifurcation curves in biological models, Tent and logarithmic functions, Smale horseshoe, solenoid: topological, combinatorial, measure theoretical properties, Chaos in the Lorentz model

Literature: P. Glendinning: Stability, Instability and Chaos, Cambridge University Press, Cambridge, 1994; C. Robinson: Dynamical Systems, CRC Press, Boca Raton, 1995; S. Wiggins: Introduction to Applied Nonlinear Analysis and Chaos, Springer, Berlin, 1988

Evolutionary game theory (2/0/0/e/3)
Responsible lecturer: Szabó György (Szunyogh László)

This course gives an introduction to the multi-agent evolutionary games building on statistical physics knowledge gained while earning a BSC degree in Physics. The following topics are discussed: Concepts of traditional game theory (strategy, payoff, matrix game, Nash equilibrium, etc.); Evolutionary games with population dynamics; Evolutionary games on lattices and graphs; Generalization of dynamical pair approximation. Many interesting phenomena are described by considering the repeated multiagent Prisoner's Dilemma and Rock-Scissors-Paper games for different connectivity structures.

Literature: Karl Sigmund: Az élet játékai (Akadémiai Kiadó, Budapest, 2003); J. Hofbauer and K. Sigmund: Evolutionary Games and Population Dynamics (Cambridge University Press, 1998);
G. Szabó and G. Fáth: Evolutionary games on graphs, cond-mat/0607344.

Complex networks (2/0/0/e/3)
Responsible lecturer: Török János

The aim of the course is to give an introduction to the rapidly developing interdisciplinary field of complex networks. Topics to be discussed: Complex systems and their scaffold. Percolation theory. Erdős-Rényi and small world graphs. Scale free networks. The configuration model. Networks growth models. Local and hierarchical structures. Communities. Spreading. Temporal networks. Social networks. Economic networks. Ecological networks. Project presentation.

Literature: A.-L. Barabási: Linked (2002), M. E. J. Newman: Networks: An introduction (2010)

Artificial intelligence in data science (1/2/0/e/5)
Responsible lecturer: Török János

The aim of the course is the give a practice oriented introduction to neural network and other classification methods used in data science with the aim to understand the underlying mathematical and statistical problems. The covered subjects are: Image segmentation, Decision tree, Random fores, Deep learning, backpropagation, Higher level implementations (tensorflow, sklearn, keras), Convolutional neural networks, Pre trained models, Textual data, Sequential data, Game models

Optics subject group

Physical Optics (2/1/0/e/5)
Responsible lecturer: Koppa Pál

The main goal of the course is to introduce modern light propagation models and to practice their use for the description of basic optical phenomena. Based on the classical electromagnetic wave theory the following topics are discussed: propagation in homogenous isotropic and anisotropic media, optical thin films, dielectric waveguides, geometrical optics and Fresnel-Kirchoff diffraction theory.

Literature: Born–Wolf: Principles of Optics (Pergamon Press), Saleh–Teich: Fundamentals of Photonics (John Wiley & Sons).

Laser physics (2/0/0/e/3)
Responsible lecturer: Maák Pál

This course is the continuation of the Laser technique course. Semi-classical and quantum theory of the laser. Frequency and bandwidth of the laser modes. Second harmonic generation, non-linear polarization, phase matching, parametric oscillation. Ultra short pulses. Mode synchronization, pulse compression, chirped mirrors. Fiber lasers and solitons. Tunable ultra short pulses. Pulse shaping. Generation and measurement of TW ultra short and attosec pulses.

Literature:
O. Svelto, Principles of lasers, Springer 1998 (4. kiadás);
W. Demtröder: Laser Spectroscopy, Vol 2: Experimental Techniques, Springer 2008 (4. kiadás)

Optoelectronic devices (2/0/0/e/3)
Responsible lecturer: Barócsi Attila

This course describes the principles and operation of modern optoelectronic devices built on knowledge in solid state physics and optics gained during a BSc study in Physics. The following topics are discussed: foundations of radiometry and photometry, light-matter interaction and semiconductor light sources, external photoeffect based detectors, semiconductor photon detectors, matrix detectors, spatial light modulators, special architecture (electro-, acousto- and nonlinear optical) devices.

Literature: Saleh-Teich: Fundamentals of Photonics 2nd Edition (ISBN 978-0-471-35832- 9, John Wiley, 2007), Safa Kasap: Optoelectronics & Photonics:Principles & Practices: International Edition 2nd Edition (ISBN 9780273774174, Pearson, 2013).

Optical materials and technologies (3/0/0/e/5)
Responsible lecturer: dr. Kocsányi László

This is the first part of a two-semester MSc course. Based on electromagnetic light theory and solid state physics we make students acquainted with the practical application of the light-matter interaction. The characteristics of most important isotropic optical materials (glasses, plastics, metals, etc.) of bulk optical elements applicable in the UV, visible and infrared wavelength region will be discussed. We introduce students to the production technologies and tools, including the manufacturing of surfaces (cutting polishing grinding etc.) and to complete series of technological steps of the fabrication of different bulk devices. We summarize the most important quality measuring methods and devices. We discuss special case studies and visit an optical workshop with the purpose to make candidates qualified for the speculative production of simple bulk optical elements.

Literature:
Born M., Wolf E.: Principles of Optics, Pergamon Press 1959; Pohl, R.W.: Optik und Atomphysik, Springer Verlag, Berlin-Göttingen-Heidelberg, 1963; Joseph H. Simmons, Kelly S. Potter: Optical Materials, Academic Press, 2000, Horne, D.F.: Optical Production Technology, Adam Hilger 1983, ISBN 0-85274-350-5.

Optical information processing and data storage (2/0/0/e/3)
Responsible lecturer: Maák Pál

This course is based on the knowledge gained in the BSc physics courses and in the Optics course. Students get a detailed overview of the classical and modern optical image and information processing methods and systems. The course starts from the classical coherent and incoherent image processing, correlating and comparison techniques, giving a detailed description of the many different systems developed for this purpose, including their physical basis, parameters, advantages and limitations. As a result of further development started from the classical information processing, new applications of the former techniques are presented in detail: optical data storage, optical computing and optical radar systems. Basic building blocks, like acousto-optic, magneto-optic, electro-optic devices, whereas different SLM-s, optical switches and scanners are treated in detail. The technology and broad application area of ultrashort pulsed lasers is also part of this course.

Literature: S. H. Lee, et al. Optical Information Processing, S. H. Lee, editor, Springer- Verlag, New York, 1981, J. W. .Goodman, Introduction to Fourier Optics, J, (2. nd. Edition), McGraw- Hill, 1996, N. J. Berg, editor, Acousto-Optic Signal Processing, Marcel Dekker Inc., New York, 1983, Saleh, Bahaa E. A. / Teich, Malvin Carl Fundamentals of Photonics Wiley Series in Pure and Applied Optics. 2. Edition – 2007, International Trends in Applied Optics Editor(s): Arthur H. Guenther ISBN: 9780819445100 2002.

Optical Metrology (2/0/0/e/3)
Responsible lecturer: Kornis János

The goal is to present an overview of the methods of optical metrology and present the most recent techniques and results. Topics: Elements of the optical measuring systems. Light sources, detectors, recording materials. Measurement of optical properties of the optical elements. Measurement of angle, length, and flatness by classical methods and using coherent optics. Heterodyne and phase stepping interferometry. Holography and speckle metrology. Digital holography. Application of optical signal processing in speckle metrology. Photo elasticity. Optical fiber sensors. Color measurement, optical metrology based on detection in different colors.

Literature: K. J. Gastvik: Optical Metrology, John Wiley&Sons, New York 1995, R.J. Keyes: Optical and infrared detectors, Springer Verlag 1980, R. S. Sirohi: Optical Components, Techniques, and Systems in Engineering, John Wiley&Sons, New York 1992.

Fundamentals of optical design (2/2/0/e/6)
Responsible lecturer: Erdei Gábor

Based on the fundamental knowledge in optics obtained while earning the Applied physics BSc degree, this course describes the concepts and models used for designing optical imaging systems, presents their usual evaluation methods and the theory of operation of the most significant imaging devices. In the frame of this course students discover the possibilities of optical design software and learn their usage on a basic level, as well as practice the steps of the design process. Though incompletely, we also deal with taking into account the effects of fabrication errors, and learn the basic concepts of lens mounting techniques.

Literature: W. J. Smith, „Modern Optical Engineering”, McGraw-Hill; J. W. Goodman, „Introduction to Fourier Optics”, McGraw-Hill

Light sources (2/0/0/e/3)
Responsible lecturer: dr. Kocsányi László

The goal of the course is to introduce physicist-, electrical engineer- and chemical engineer students to the science and technology of light sources. The thematic includes the overview of the usual photometric parameters, the survey of the development of lamps from incandescent light sources, through discharge lamps to LEDs, the basic physical processes, and the comparison of the advantages, disadvantages and possible fields of application of different lamp types.

Literature: Elenbaas, W.: Light sources, Macmillan, 1972, Cayless, M.A., Marsden, A. M.: Lamps and Lighting, Arnold, 1997.

ELI Preparatory Laboratory (0/0/4/c/4)
Responsible lecturer: dr. Maák Pál

The task of this laboratory course is to give preparation for the students in modern optical metrology by learning the handling of modern measuring instruments and building optical setups. These laboratory exercises are related to the newest research topics in the field of laser technology and phtonics. The practices are performed on modern and expensive instruments and tools: femtosecond lasers, amplifiers, Terahertz sources, nonlinear optical materials, adaptive optical system, and the characterization tools needed for high power or ultrashort pulsed laser radiation: interferometers, spectrometers, autocorrelators, frequency resolved optical gating instrument. The course provides the basic skills needed for a successive participation in the research and development topics at Hungarian laser institute, the ELI-ALPS facility.

Literature: Wolfgang Demtröder: Laser Spectroscopy Vol. 2., Springer, 2008, B.E.A. Saleh et al: Fundamentals of Photonics 2-nd ed., Wiley, 2007.

Design and Construction of Laser Systems (2/0/0/c/3)
Responsible lecturer: dr. Maák Pál

This course deals with the design and construction of laser oscillators and amplifiers, mainly based on solid state (crystal) amplifier material, bad gas amplifiers, fiber lasers and semiconductor laser diodes are also overviewed. Detailed design description is given for cw, Q-switched and mode-locked solid state laser design, including amplification optimization, thermal analysis, cooling techniques and pumping geometries. We also treat amplifiers: regenerative and multipass arrangements including advanced configurations like innoslab and thin disk amplifier techniques. Special section is devoted to amplification of ultrashort pulses, chirped pulse amplification, stretching and compressing of these pulses, design of the dispersion management and pulse shaping techniques. Here we introduce methods for carrier envelope phase stabilization and generation of special waveforms, frequency combs. An other discussed topic is parametric amplification where obtainable parameters, techniques, design conditions are treated. The course gives advanced preparation for laser specialists at both engineering and research level.

Literature:
W. Köchner: Solid State Laser Engineering, Springer London, Limited, 2006
R. Paschotta: Encyclopedia of Laser Physics and Technology, John Wiley & Sons, 2008
S. Watanabe: Ultrafast Optics V, Springer, 2007

Infrared and Raman Spectroscopy (2/0/2/e/6)
Responsible lecturer: Dr. Richter Péter

Interaction of electromagnetic radiation and matter: absorption, emission, scattering. Infrared absorption and Raman-scatteringin molecules, vibrational transitions. Connection between selection rules and molecular symmetry. Infrared and Raman excitations in solids.Discussion of lattice vibrations and low energy electronic transitions using the dielectric formalism. coupled electron-phonon excitations.Foundations of the FTIR method instrumental lines-shape, apodization, phase correction, zero filling. Properties of light sources, monocromators, detectors. Absorption and reflection measurements, determination of the dielectric function.Following phase transitions by spectroscopy. Qualitative and quantitative analysis. Infrared microscopy.

Literature: P.R. Griffiths, J.A. De Haseth: Fourier Transform Infrared Spectrometry, Wiley-Interscience, 2007, D.A. Long: Raman spectroscopy, McGraw-Hill, 1977

Fundamentals of Photonics (2/1/0/e/5)
Responsible lecturer: dr. Barócsi Attila

Based on general knowledge in optics, the course aims at getting students familiarized with the rapidly expanding field of modern photonics. Photonics is advancing into the forefront of applications where electronic devices approach their speed and bandwidth limits. The course expressively, recalling only the necessary mathematic, physical and optical tools, reviews the photonic devices describing their operation and illustrating their application.).

Literature:
S.O. Kasap: Optoelectronics and Photonics: Principles and Practices, 2nd Edition (2013) Pearson, ISBN: 0-13-215149-9
B.E.A. Saleh, M.C. Teich: Fundamentals of Photonics, 2nd Edition (2007) John Wiley & Sons, ISBN: 978-0-471-35832-9

Quantum Optics (2/1/0/e/5)
Responsible lecturer: Domokos Péter

The course is an introduction to quantum optics. The topics covered are:1. Coherence in classical optics2. Radiative transitions in quantum matter, atoms and semiconductors3. Photodetection, photon statistics, super- and sub-Poissonian light4. Hanbury-Brown and Twiss interferometry, photon antibunching5. Coherent and squeezed states, Wigner functions6. Resonant light-atom interaction, density states, Rabi oscillation7. Atoms in cavities, Purcell effect, strong coupling8. Cold atoms, Bose condensation, optical lattices9. Quantum cryptography and quantum information10. Entanglement, quantum teleportation, Bell inequalities

Literature:
Quantum Optics: an Introduction, Mark Fox, OXFORD MASTER SERIES IN PHYSICS, Oxford University Press 2006, ISBN-13: 978–0

Industrial and Biological Applications of Lasers (2/0/0/e/3)
Responsible lecturer: dr. Maák Pál

The course provides a comprehensive overview of the applications of lasers and a wide variety of instruments and equipment based on laser technology. The topics of the course include: Industrial laser applications, introduction and characterization: material and non-material applications. Laser-material interactions, characteristics of materials and lasers. Laser processing of material surfaces: heat treatment, surface melting, surface hardening, surface coating, alloying, surface hardening and cleaning. Laser volume machining. Material removal: drilling, cutting, engraving, marking, welding, trimming. Non-machining applications: line and level alignment, length and distance measurement, barcode reading, rapid prototyping. Application of lasers to measure surface quality and shape, surface quality measurement based on reflection and scattering, scanning interferometric surface measurement (Talysurf), atomic force microscopy. Application of interferometry to measure surface quality and shape, low coherence interferometry, typical applications and instruments. Laser based techniques in the semiconductor industry. Laser microscopy in industry and medicine, fluorescence and reflection confocal microscopy, optical coherence tomography, types and applications. Principle and technical basis of two-photon microscopy. Use of lasers in diagnosis and therapy. Interaction of laser light and biological tissues. Laser diagnosis methods. Advantages and disadvantages of laser surgery. Laser treatment of tumors. Special laser applications: medical holography, laser tweezers, laser particle acceleration and application for hadron therapy, laser fruit sorting equipment, lasers in artificial intraocular lens technology and development.

Literature:
R. Paschotta: Encyclopedia of Laser Physics and Technology, John Wiley & Sons, 2008
Demtröder: Laser Spectroscopy Vol. 1-2, 4. th edition, Springer, 2008;
saját jegyzet Bevezetés a modern

Fundaments and Applications of Nonlinear Optics (2/0/0/e/3)
Responsible lecturer: dr. Papp Zsolt József

Optical data transfer: eikonal equation, sandwich structure, single and multimode optical fibers, modes, dispersion, energy relationships, fiber optic couplers, meta-materials, coupled modes, perturbation theory, DFB laser, fiber laser, fiber amplifiers, fiber optics control, other applications (fiber optic measurements, optical gyroscope, etc.) Nonlinear optics: crystal optics, nonlinear (classical) optics, theory of optical activity, Jones calculus, linear and quadratic electro-optical phenomena (Kerr, Faraday, Zeeman, Cotton-Mouton effect) , etc.), nonlinear crystals, second harmonic excitation, Maxwell-Bloch equations, rotary wave approximation, inhomogeneous line broadening, self-induced transparency, phase modulation, saturation phenomena, nonlinear spectroscopy, progressing wave amplification, parametric processes, self-focusing, fundaments of nonlinear pulse propagation, solitons, attenuation, dispersion, twin photon generation. Applications: quantum eraser, quantum teleportation, QKD, CQKD, photon state measurement, etc.

Literature:
Nussbaum & Phillips: Moder optika, Allen & Eberly: Optical resonance and two-level atoms
Mandel & Wolf: Optical coherence and quantum optics
Nussenzweig: Introduction to quantum optics

Materials Science subject group

Electron- and ionoptics (2/0/0/e/3)
Responsible lecturer: Hárs György

The course deals with the discussion of generating, analyzing and detecting charged particles, as well as the overview of the applications is provided. In the course the following subjects are discussed: electron and ion sources, energy analyzers, mass analyzers, general considerations of the trajectories in case of electric and magnetic fields, particle accelerators, space charge effects, detection modes of charged particles.

Electrical and optical properties of solids (2/0/0/e/3**)**
Responsible lecturer: Gali Ádám

This course prescribes the knowledge of fundamental solid state physics and quantum mechanics from BSC education in Physics. In this course it is schematically explained how the structure is formed in different type of solids due to the different type of forces that bind them. The electronic structure of typical metals and semiconductors is reviewed and explained how that can be measured or calculated. The semiconductors are defined from technological point of view. Typical carriers in semiconductors are defined and explained how they can be measured or calculated. The dynamics of Bloch-electrons is reviewed within semi-classical treatment, and the basic definitions needed for understanding the function of semiconductor devices are explained (Fermi-level, n and p-type conduction, excitonic states). It is shown how the point defects influence the electronic band structure of the semiconductors: definition of doping, thermal point defects. The electronic structure and the density of states of low-dimensional systems as well as the amorphous solids are examined. Finally, the interaction of the electromagnetic radiation with the matter is explained for metals, semiconductors and insulators.

Literature: Kittel: Introduction to solid state physics; Sólyom Jenő: Fundamentals of moder physics of solids I-II

Vacuum physics and technology (2/0/0/e/3)
Responsible lecturer: Hárs György

Vacuum environment is necessary at some of the experimental techniques and manufacturing process. Physics of vacuum as well as the related technological skills (pumping, maintaining and measuring) are needed to operate and to construct vacuum systems. In the course the following subjects are discussed: laws of the gas phase, concept of vacuum, transport phenomena in vacuum, interaction between gaseous and condensed phase, pumps, vacuum measurements, leak testing, materials used in vacuum technology.

Literature: Roth, Vacuum technology, Elsevier 1982, Carpenter, Vacuum technology, Hilger Bristol, 1983.

Material Science Laboratory (0/0/3/c/4)
Tárgyfelelős/Responsible lecturer: Homokiné Dr. Krafcsik Olga

The goal of the course is an introduction - in the field of materials science - to material characterization measurement methods and technologies on theoretical level and in practice also. On each laboratories a measurement method, technical conditions of sample preparation and measurement, evaluation and informations obtained from measurements will be introduced. Practical measurement examples and technological informations obtained from the measurement will be demonstrated. In the lab, as far as possible, the students perform the sub-tasks independently. In some cases the measuremens will be connected to a technological lab by a „miniproject", in this way students can get an overview from sample preparation to measurement evaluation in a specialization field of materials science.
The chosen methods will be demonstrated by experts in Budapest, on the latest available equipments.
Planned measurements: vibrational spectroscopies, infrared spectroscopy, Raman spectroscopy, Electron diffraction, X-ray diffraction, NMR, ESR, Measurements on Semiconductor structures.

Literature: Actualized Measurement guides and lecture notes according to the laboratory measurement projects

Fundamentals of Surface Physics (2/0/0/c/3)
Responsible lecturer: Homokiné Dr. Krafcsik Olga

The aim of this course is to help BsC students to learn the basic concepts and measurement techniques of surface physics by presenting application examples.
Main topics discussed include: Surface and interface physics: Its definition and importance, Preparation of well-defined surfaces, interfaces and thin films, Morphology and structure of surfaces, interfaces and thin films, nucleation, surface structure measurement techniques, Adsorption on Solid Surfaces, Physisorption, Chemisorption, Work-function and its measurement techniques, Bulk and Surface Diffusion, Surface analytical measurement techniques and their comparison.

Literature:
H. Ibach: Physics of Surfaces and Interfaces 2006
H. Lüth: Solid Surfaces, Interfaces and Thin Films

Surface Physics and Thin Films (2/0/0/c/3)
Responsible lecturer: Homokiné Dr. Krafcsik Olga

This course covers the main field of physics of surfaces and thin layers, based on solid state physics fundamentals. A detailed description is given on the structure and electronic structure of surfaces. Space charge region, work function, semiconductor/semiconductor, semiconductor/metal and semiconductor/insulator interfaces, lattice vibrations of surfaces, adhesion, surface reactions and transport phenomena are also discussed.

Literature:
F. Bechstedt: Principles of Surface Physics, Springer, 2003
Ibach: Physics of Surfaces and interfaces, Springer, 2006

Basic materials science and its applications (2/0/0/e/3)
Responsible lecturer: Dr. Réti Ferenc

The scope of this course is to give basic knowledge in modern materials science and its application in selected fields of physics and engineering. Topics treated: Materials science and engineering. Modern materials, requirements during their use. Role of primary and secondary bonds in the properties of materials. Importance of thermal properties, thermodynamics, thermochemistry, Hess law, Born-Haber cycle. Chemical potential, equilibrium constant. Equations of reaction kinetics. Arrhenius and Eyring equations. Importance of crystal defects, e.g. in electrical and mechanical properties. Equilibrium concentration of crystal defects. Sensors in engineering. Principles, physical and chemical sensors. Pressure gauges, thermometers, load cells, magnetic sensors. Non-destructive testing. Ultrasonic crack testing, X-ray testing, magnetic tests. Exemples. Alternative energy sources and energy carriers; contradictions. Hydrogen economy, bio-ethanol. Fuel cells as continuous batteries.

Literature: P.W.Atkins, Fiziai-kémia, Tankönyvkiadó, 2002, W.D. Callister, Jr.: Materials Science and Engineering, An Introduction, John Wiley and Sons Inc., 6th edition, 2003

Physical materials science (2/0/0/c/3)
Responsible lecturer: Dr. Réti Ferenc

The course – basing on the knowledge of physics obtained during B.Sc. - through exemples gives knowledge in modern materials science. Topics treated: Role of chemical bonds in materials properties. Secondary bonds. Crystal structure, unit cell, crystallographic directions and planes. Single crystals, polycrystalline materials, anisotropy, non-crystalline materials. Polymorphism and allotropy. Carbon and silicon in materials science. Carbon and silicon allotropes, their properties. Monomers, oligomers, polymers. Chemistry of polymers, molecular weight, shape and structure of molecules. Copolymers. Crystalline polymers. Polymers and plastics, additives. Composites. Diffusion mechanisms. Surface and grain boundary diffusion. Diffusion in ionic materials and polymers. Mechanical properties of metals, ceramics and polymers, stress and elastic strain. Slip, plastic deformation. Theoretical base of cracking, mechanisms, fatigue, creep. Planning, risks, security coefficients. Phase diagrams: solubility limit, phases, microstructure, phase equilibria. C – Fe system. Phase transformations. Mechanism of solid phase reactions in metal alloys. Melting, crystallisation and glass transition in polymers. Electronic and ionic conduction, band structure of solids, electron mobility, resistance of metals. Semiconductors. Ion-conducting ceramics and conducting polymers, dielectrics. The phenomenon of corrosion. Magnetic properties of materials

Literature: W.F. Smith, J. Hashemi: Foundations of Materials Science and Engineering, McGraw-Hill, Third edition 2004., W.D. Callister, Jr.: Materials Science and Engineering, An Introduction, John Wiley and Sons Inc., Sixth edition, 2003.

Micro- and nanotechnologies (2/0/0/c/3)
Tárgyfelelős: Dr. Kiss Gábor

Definition, comparison of microtechnology, nanotechnology and molecular nanotechnology. Conditions of the technology. Micro- and nanophysics. Methods of thin film deposition: physical methods (vacuum evaporation, laser ablation evaporation, molecular beam epitaxy, sputtering), chemical methods (chemical vapour deposition, chemical solution deposition). Doping (diffusion, ion implantation). Litography (photo-, X-ray, electron / ion beam litography). Layer removing technologies: wet „chemicaal" etching, dry etching (plasma, ion beam). Layer examination methods: XRD, TEM, SEM, SIMS, XPS, STM, AFM. Thick layer technologies: screen printing, burning, pastes. Nanoscale devices, micro-electromechanical systems, molecular nanotechnology.

Literature: C.Y.Chang and S.M.Sze (Ed.): VLSI Technology, McGraw Hill, 1996., R. Waser (Ed.): Nanoelectronics and ionformation technology, Wiley-VCH, 2003.

Trends in materials science (1/0/0/e/2)
Responsible lecturer: Dr. Kiss Gábor

The goal of this course is to give knowledge on the materials science processes, the tasks and possibilities of the materials science, the requirements of the national and international market on the basis of the lectures given by invited lecturers, coordinated by the lectures of the coordinator. The main point of view is to demonstrate the connection of modern life to the materials science, to present its importance. Topics of special interest: material- and energy-economic processes in bulk, alloying, metallic, non metallic and composite structural materials, corrosion, special requirements towards semiconductors, plastics, organic and biomaterials etc. The thematic is flexible. The lectures: Problems of the nanoscience, Metallic nanocomposites, Nanotechnology in microsystems, Thin layers, Mechanical alloying and its application with special regard on the preparation of nanostructured materials, Semiconductors, Emission materials, Technological and materials science aspects of light sources, Solid electrolyte capacitors, Integrated optics and its applications, Oxide semiconductor based chemical gas sensors.

Spectroscopy and structure of matter (2/0/0/e/3)
Responsible lecturer: Richter Péter

This course organizes the knowledge obtained during the BSc training (electrodynamics of media, quantum mechanics, group theory, statistical physics, optics, optical measurement techniques) regarding the use of spectroscopy in materials characterization and structure elucidation. The methods covered are mainly optical techniques (infrared and visible/UV absorption and reflectance spectroscopy, Raman scattering, ellipsometry, optical rotation dispersion, circular dichroism) but other topics, as excitations of inner shells (X-ray and photoelectron spectroscopy, Mössbauer spectroscopy) will also be mentioned. The purpose of the course is to prepare the students to decide which spectroscopic methods to use for a given specific problem, and to be abel to basically interpret the results.

Literature: G. R. Fowles: *Introduction to Modern Optics*. Dover, 1989, F. Wooten: *Optical Properties of Solids*. Academic Press, 1972, H. Kuzmany, *Solid State Spectroscopy, an Introduction* Springer, Berlin, Heidelberg, 1998.

Nuclear Techniques subject group

Basics of atomic energetics (3/2/0/c/5)
Responsible lecturer: Szieberth Máté

Lecture: history of nuclear energy. Bases of reactor physics and reactor techniques. Bases of reactor heat techniques. Bases of radiation protection. Construction and equipment of NPPs, safety, accidents. Environmental effects. Economy of nuclear electricity production. Position of nuclear energy in the cooperative electricity system, nuclear systems.

Practice: reactor physical calculations: multiplication factor, reactivity, neutron flux, doubling time, conversion factor, xenon poisoning. Heat technical calculations: power density, temperature distribution, remanent heat calculation. Radiation protection calculations: half-thickness, dosimetry calculations. Calculation of production costs.

Nuclear Power Plants (3/1/0/e/5)
Responsible lecturer: Aszódi Attila

Introduction of Gen. II, III and IV reactors. Comparison of thermal circuit schemes of different NPP types, introduction of primary and secondary side systems and components. Corrosive and erosive processes in the primary and secondary circuits, theory and implementation of primary and secondary side water chemistry. Air filtering and venting systems. Buildings and rooms receiving technology equipment. Build-up of the control room, implementation of ergonomic and accident management aspects. Special aspects of electric systems' construction. Different types of operational and emergency cooling systems. Aspects of NPP siting.

Material Testing in Nuclear Power Plants (2/0/0/e/3)
Responsible lecturer: Aszódi Attila

Inspection methods of primary and secondary side main equipments of PWR power plants. Testing methods, fault detecting techniques. Testing methods of reactor pressure vessel and steam generator. Visual inspection methods, manipulation techniques, application of telemechanics. Special methods for checking the shape- and size adequacy. Inspection of fresh and irradiated fuel bundles (tightness testing, thermal hydraulic investigation, tomography methods). Inspection methods for radwaste containers. Nuclear material testing methods (radiography, tomography etc.).

Chemistry in Nuclear Power Plants (2/1/0/c/4)
Responsible lecturer: Szalóki Imre

The major types of chemical and radiochemical processes of the nuclear power plants (NPP) are discussed according to the following topics: water chemistry of NPPs, radioisotopes in the fuel and the coolant, fuel performance evaluation, corrosion processes, water purification systems, decontamination, radioactive waste treatment, environmental monitoring, radioanalytics in NPPs. Visit to Paks NPP will be organized.

Literature: K.H. Neeb: The Radiochemistrey of Nuclear Power Plants with Light Water Reactors (Walter de Gruyter, Berlin, 1997), V.V. Geraszimov, A.J. Kaszperovics, O.J. Martinova: Atomerőművek vízüzeme (Műszaki Könyvkiadó, Budapest, 1981).

Nuclear power plant operation (2/2/0/c/5)
Responsible lecturer: Czifrus Szabolcs

The course focuses on the parameters of an NPP important for the operation. Students study the reactivity feed-back effects and their influence on the operation and safety of NPPs, the operational aspects of xenon and samarium poisoning, the spatial power density distribution and related thermal and operational limits, parameter changes during a cycle, special operational aspects at the end-of-cycle. We present the on-line core monitoring methods and the in-core and ex-core detectors applied. Furthermore, the core analysis codes, the methods of data acquisition, the basics of data processing and on-line fuel condition monitoring are discussed in detail. The course is closed with the introduction to reactor pressure vessel problems and monitoring, and the operation of reactor control instrumentation.

Radioanalytics (3/0/2/c/6)
Responsible lecturer: Szalóki Imre

The course describes the fundamentals of radioanalytics based on the knowledge about radiochemistry gained while earning a BSC degree in Physics. The major topics to be discussed are the following: analysis of radionuclides by means of radiochemical procedures and nuclear measuring techniques, application of nuclear methods for the analysis of the elemental composition and material structure. During the laboratory exercises „difficult-to-determine” nuclides e.g. uranium and transuranium isotopes, strontium-90 will be analyzed.

Literature: G. Choppin, J.O. Liljenzin, J. Rydberg: Radiochemistry and Nuclear Chemistry (Reed Educational and Professional Publishing Ltd., Oxford, 1996), K.H. Lieser: Nuclear and Radiochemistry (Wiley-VCH, Berlin, 2000).

Nuclear fuel cycle (2/1/0/c/4)
Responsible lecturer: Szieberth Máté

The course intends to provide an overview on the whole nuclear fuel cycle based on the nuclear physics knowledge gained during the physics BSc course. The major topics to be discussed are the following: structure of the nuclear fuel cycle; uranium sources and supply; uranium mining and ore conversion; isotope enrichment; fuel fabrication; general technical characteristics of nuclear power plants; thermal reactor based power plants; fast reactors based power plants; managing and reprocessing of spent fuel; reprocessing methods; managing and final disposal of radioactive waste; partitioning and transmutation; safety related issues; feasible nuclear fuel cycles; once-through cycle, closed fuel cycle; fuel management characteristics of nuclear power plants; symbiotic nuclear energy systems, fuel management characteristics of symbiotic systems; development trends in nuclear energy systems.

Nuclear non-proliferation (2/0/0/e/3)
Responsible lecturer: Csige András

Basic knowledge in nuclear physics. Binding energy of nuclei. Nuclear reactions. Fission and fusion. The nuclear chain reaction. Uranium enrichment and its technologies. Nuclear weapons based on nuclear fission. Nuclear weapons based on nuclear fusion. Information from atmospheric and underground test. Miniaturization and simulations. Technological and physical basic information for the safeguards. Importance of nuclear weapons, nuclear doctrines, nuclear strategies of NATO. The elements of the non-proliferation system. History of the nuclear non-proliferation. Hiroshima, Nagasaki, the atomci age and the cold war. The main statements of the NPT, the supervision conferences, the enlargement and the PrepCom /1997/. The „threshold” states, the „de facto” nuclear states, the potential threshold states and the former Soviet states. The nuclear-free zones on habited and inhabited areas. The history of nuclear tests, the efforts for limiting them. PTBT, CTBT. Positive and negative security guaranties. The „no first use” principle. Verification systems, and their problems. International export controlling systems. The future of nuclear non-proliferation and safeguards, and its relevance to Hungary.

Literature: Kenneth S. Krane: Introductory Nuclear Physics (1988), Jozef Goldblatt: Arms Control. A Guide to Negotiations and Agreements (1994); The NPT and the supervision conference in 1995, (In Hungarian)

Nuclear Energetics and Sustainable Development (2/0/0/c/3)
Responsible lecturer: Aszódi Attila

Definition of sustainable development, international agreements, development of electricity production methods, their role in the sustainable development, energy source supply, fossil energy sources and their mining, security of energy supply, relation of energy supply and economic independence, global warming, Kyoto protocol, climate protection, role of renewable sources and nuclear energy in a healthy energy-mix, structure and types of nuclear reactors, comparison of different energy production methods, nuclear energy systems, radioactive wastes, safety of nuclear power plants and environmental effects, Tsernobyl.

Introduction to fusion plasma physics (2/0/0/e/2)
Responsible lecturer: Gergő Pokol

General introduction to plasma physics. Energy generation with fusion reactors, Lawson criterion, parameters of fusion plasmas. Inertial fusion. Collisionless motion of charged particles in magnetic field. Thermodynamic equilibrium, ionization and radiative processes in the plasma. Magnetic confinement: configurations. Particle collisions in plasma, transport processes. Plasma theory: kinetic description, fluid description, MHD. Equilibrium and instabilities in magnetically confined plasma, plasma waves. Laboratory plasmas: breakdown, plasma heating, plasma-wall interaction. Plasma diagnostics, measurement methods. Recent results, achievements in fusion plasma confinement.

Literature: Pokol Gergő, Zoletnik Sándor, Papp Gergely, Horváth László: Introduction to fusion plasma physics (lecture notes)

Fusion devices (2/0/0/e/3)
Responsible lecturer: Gergő Pokol

The course briefly introduces the theory of magnetic confinement fusion, and the technology needed for the practical realization. It continues with a historical overview and the detailed description of today's most important – already operating or still under construction – tokamaks and stellarators. We discuss the basic principles of design and operation, main components and auxiliary systems of the ASDEX-Upgrade, the JET and the ITER tokamaks, the Wendelstein 7-X stellarator and other devices selected in view of their most recent results. The course accommodates the presentation of the main Hungarian developments, briefly covers the further way towards fusion energy production and provides guidance in autonomous research in the topic.

Literature: Pokol Gergő, Lazányi Nóra: Fusion devices (lecture notes)

Collisional transport in magnetized plasma (1/2/0/c/4)
Responsible lecturer: Gergő Pokol

Kinetic and fluid descriptions of a plasma. The collision operator. Plasma fluid equations. Transport in cylindrical plasma. Particle motion. Toroidal plasmas. Transport in toroidal plasmas. Transport in the Pfirsch-Schlüter regime. Transport in the plateau regime. Transport in the banana regime.

Literature: Per Helander and Dieter Sigmar: Collisional transport in magnetized plasmas (Cambridge University Press, 2002)

Instrumentation and control of nuclear reactors (2/1/0/e/4)
Responsible lecturer: Pór Gábor

From details of temperature, pressure, vibration sensors and nuclear detectors applied in contemporary nuclear power plants via problems of building and maintaining measuring chains to data collection and data processing, to data evaluation. Safety consideration including principles of two from three, and independence of signals, international standards including recommendations of IAEA and nuclear authorities, man-machine interface including nuclear power plants control room and operator support systems. Detailed studies in high-tech nuclear measuring methods and systems like VERONA, C-PORCA, PDA, core diagnostics, loose parts monitoring, vibration monitoring, leakage monitoring, acoustic monitoring ageing monitoring systems built in NPP. Short survey of future trends like wireless measuring systems, testing of digital software for I&C, artificial intelligence for operator support systems.

Health physics II (2/0/2/e/5)
Responsible lecturer: Zagyvai Péter

This course describes the determination of external and internal dose due to natural and – occasionally – artificial sources of generally low radioactivity based on nuclear physics and radiation protection knowledge gained while attending a BSC course in Physics. Topics discussed: detailed analysis of dose concepts, special problems (KERMA versus absorbed dose, equivalent and effective dose for assessing stochastic radiation effects), health physics control and regulation based on dose/risk dependence, principles and practice of dose and dose rate measurement, calculation of internal exposure, nuclear analysis for determining internal dose, compound radiation measurements: radon analysis, nuclear environmental monitoring.

Literature: Köteles Gy.: Sugáregészségtan (Medicina, Budapest, 2002.), Kanyár B.: Radioökológia és környezeti sugárvédelem (Veszprém, 2000.), Letölthető jegyzetek a Nukleáris Technikai Intézet interenetes oldaláról. / Downloadable lecture outlines from the web site of the Institute of Nuclear Techniques.

Neutron and gamma transport calculation techniques (2/1/0/c/4)
Responsible lecturer: Czifrus Szabolcs

The course helps students practically apply their knowledge gained during the „Reactor physics” course in Physics BSc. In the lectures and exercises of the course we first present simple radiation shielding problems the solution of which can be performed using approximate methods. Here students familiarize themselves with the MicroShield program. As proceeding to more advanced and complicated problems, students learn to use some of the features of the internationally acknowledged, Monte Carlo based, coupled neutron-photon-electron transport code MCNP. Students have to solve radiation shielding design problems, as well as reactor physics problems using the code.

Literature: A.B. Chilton, J.K. Shultis, R.E. Faw: Principles of radiation shielding. Prentice Hall, 1984, J.F. Briesmeister (ed.): MCNP4C - A general Monte Carlo N-particle transport code. LA- 12625-M, Los Alamos, November, 1993.

Nuclear power plant simulation exercises (0/0/2/c/3)
Responsible lecturer: Csige András

The aim of the course is to deepen the knowledge about the reactor physical and thermohydraulical processes taking place in nuclear power plants, using the simulators available at the Institute of Nuclear Techniques and the KFKI Atomic Energy Research Institute. During the course the following simulators are used: PC^2 primary circuit simulator; SSIM secondary circuit simulator; STEGENA steam generator analyzer; APROS one-dimensional thermohydraulics advanced process simulator; CFX three-dimensional thermohydraulics code; full-scope simulator of the Paks NPP.

Migration of radioactive species in environmental and biological matter (2/1/0/e/3)
Responsible lecturer: Zagyvai Péter

This course describes the transport processes of radionuclides taking place in environmental and biological media based on nuclear physics and environmental physics knowledge gained while attending a BSC course in Physics. Topics discussed: appearance of radioactivity in the environment – features of source terms. Static and dynamic transport equations, modeling. Dispersion of radioactive species in atmosphere, surface waters, soil, geological structures. Biological transport processes.

Literature: D. Petruzzelli: Migration and fate of pollutants in soils and sub-soils, (NATO ASI Series G. Ecological Sciences Vol. 32.)

Safety of radioactive wastes (1/0/1/e/2)
Responsible lecturer: Zagyvai Péter

This course describes regulation and control pertaining to radioactive wastes and key issues of safe waste management based on radiation protection knowledge gained while attending a BSC course in Physics. Topics discussed: international and national regulations – theory and practice, detailed studies on safe processing, immobilization and disposal of radioactive wastes, reprocessing of certain waste types, waste analysis.

Literature: Downloadable outlines from the web site of the Institute of Nuclear Techniques.

Physics of Nuclear Reactors (3/1/0/e/5)
Responsible lecturer: Kis Dániel Péter

Interaction of nuclei with neutrons, descriptions of the reaction. Characteristics of the neutron gas. Nuclear cross-sections. Boltzmann equation. Time dependence, criticality. Diffusion theory. Reactor kinetics. Measurement of reactivity. Numerical methods. Neutron spectrum. Slowing down of neutrons. Resonance, thermalization. Thermal reactors. Reactivity coefficients. Adjoint function and its applications. Perturbations. Burn-up.

Literature: A. M. Weinberg and E. P. Wigner: The Physical Theory of Neutron Chain Reactors, The University of Chicago Press, 1958.

Medical Physics subject group

Radiobiology (2/1/0/e/4)
Responsible lecturer*:* Pesznyák Csilla

The course will focus on the understanding of radiation effects on the whole organisms, tissues and cells, as well as on the cellular causes leading to the death of normal and malignant cells. This helps to understand why a given dose of radiation induces tumors in one case while destroys tumor cells in another case. On the basis of radiobiological knowledge one can develop new therapeutic modalities to improve the survival of cancer patients. Radiation biology helps us to understand how and why ionizing radiation can be used to examine healthy and pathological cell structures and to diagnose and treat various diseases.

Literature: Hall EJ, Giaccia AJ: Radiobiology for the Radiologist, Lippincott, Williams & Wilkins, Philadelphia, USA, 6th edition, 2006; Joiner M, van der Kogel A (eds): Basic Clinical Radiobiology, Hodder Arnold, London, UK, 4th edition 2009; Steel GG. (ed.) Basic Clinical Radiobiology, Arnold, London, England, 3d edition, 2002.

Physics of Radiotherapy *(2/0/2/e/5)*
Responsible lecturer*:* Pesznyák Csilla

Scope of the subject: to foreshow the terminology of medical physics and measurement problems connected with the radiation therapy and matters connected to the radiation treatment planning. Syllabus of the subject: the methods of determination of anatomical data (CT, MRI, PET), major irradiation techniques (teletherapy, brachyterápia), radiation sources used in the radiation therapy (classical X-ray equipments, cobalt units, linear accelerators, radioactive sources, afterloading equipments. Description of the radiation field of the equipments used in teletherapy, major methods of measurement (ionization chambers, solid state detectors (film and thermoluminescent dosimetry)), measurements of the effect of beam modifying devices (hard wedge, dynamic wedge, block, MLC). Object of brachytherapy, kinds of radiation sources and their ways of application. Checking of therapy plans, the requirements of the radiation treatment planning according to the ICRU protocol. Quality assurance, quality control, safety requirements of teletherapy and brachytherapy devices, radiation protection and radiobiology in the radiation therapy.

Literature: Review of Radiation Oncology Physics: A Handbook for Teachers and Students (Ed.: E. B. Podgorsak) Educational Report Ser. IAEA Vienna, Austria, 2003. pp. 530; Khan F.: The Physics of Radiation Therapy 2nd ed. Williams & Wilkins, 1994; Williams J.R., Thwaites D.I.: Radiotherapy Physics in Practice. Oxford Univ. Press, 1993; Johns, H. E. Cunningham, J. R.: The Physics of Radiology (Fourth Edition) Charles C. Thomas Publisher, Springfield, Illinois, USA 1983.
pp. 796.

Radiation therapy II (2/0/0/e/3)
Responsible lecturer: Pesznyák Csilla

The lecture has been organized into three major parts: (I) Stereotaxic and extracranial radiosurgery, review of most important equipment, treatment planning systems and special dosimetry. (II) Advanced Image-Guided and Biological Guided Intensity Modulated Radiation Therapy (IMRT), physical optimization, imaging for IMRT, dose calculation, delivery techniques, dosimetry and QA/QC.(III) Total skin irradiation with electron beams, their special dosimetry and treatment delivery techniques.

Literature: T. Bortfeld, R. Schmidt-Ullrich, W. De Neve, D. E. Wazer (Editors). Image- Guided IMRT, Springer 2006.

Brachytherapy (2/0/0/e/3)
Responsible lecturer*: Pesznyák Csilla*

Scope of the subject: to foreshow the dosimetric terminology, equipments and treatment modalities of brachytherapy. Syllabus of the subject: Radiation physics learning: physical properties of the applied radiation sources, fundamental dosimetric concepts, strength of source, decay law, base of dose calculations, TG 43 formalism. Dosimetric systems: the rules and properties of interstitial (Manchester, Quimby, Paris) and intracavital (Manchester, Fletcher, Stockholm) systems. Computational dosimetry: methods of source localization, image based 3D radiation treatment planning, dose-volume histograms, plan evaluation.

Treatment modalities: manual and afterloading methods. Brachytherapy dose reports: dose prescription, setting and meaning of treatment parameters, GTV, CTV, PTV, ICRU Report 38 and 58. Quality assurance, source calibration, acceptance tests, control of source position, regular controls.

Literature: A. Gerbaulet, R. Pötter, J.J. Mazeron, H. Meertens, E. van Limbergen (Editors). The GEC ESTRO Handbook of Brachytherapy, ESTRO Physics Booklet No. 8. A practical guide to quality control of brachytherapy equipment.

Quality Assurance and Legislation Issues (2/0/1/e/4)
Responsible lecturer*: Pesznyák Csilla*

Review the international and Hungarian regulations and rules of quality assurance and quality control (QA/QC) in medical physics. Description of the QA/QC measurements for X-ray therapy, external beam radiotherapy and brachytherapy. Quality control protocols for conventional and CT simulators, MRI, SPECT and PET imaging systems. Independent calculations for controlling the TPS monitor unit dose calculation. Patient dosimetry. QA/QC and safety requirements of ultrasound, angiography and mammography. International and Hungarian Standards for medical equipments.

Literature:
IAEA, Commissioning and Quality Assurance of Computerized Planning Systems for Radiation Treatment of Cancer, TRS-430,
IAEA, Comprehensive Audits Of Radiotherapy Practices: A Tool For Quality Improvement (2007),
IAEA, Specification and Acceptance Testing of Radiotherapy Treatment Planning Systems, TECDOC-1540, IAEA Quality Assurance for Radioactivity Measurement in Nuclear Medicine, TRS-454

Radiation Protection in Medical Physics (3/0/1/e/5)
Responsible lecturer: Pesznyák Csilla

This course describes the determination of external and internal dose due to natural and – occasionally – artificial sources of generally low radioactivity based on nuclear physics and radiation protection knowledge gained while attending a BSC course in Physics. Topics discussed: detailed analysis of dose concepts, special problems (KERMA versus absorbed dose, equivalent and effective dose for assessing stochastic radiation effects), health physics control and regulation based on dose/risk dependence, principles and practice of dose and dose rate measurement, calculation of internal exposure, nuclear analysis for determining internal dose, compound radiation measurements: radon analysis, nuclear environmental monitoring. Patient dosimetry, radiation protection of radiotherapy and nuclear medicine.

Literature: IAEA STS No 47. Radiation Protection in the Design of Radiotherapy Facilities. Sugárvédelem, szerk.: Fehér István és Deme Sándor, ELTE, Eötvös Kiadó, 2010

Magnetic resonance and its clinical applications (2/0/0/e/3)
Responsible lecturer: Jánossy András

Objective of the course is to give an introduction to concepts of magnetic resonance and its clinical use and to discuss measurement issues and practical applications. Detailed subjects: history, the place of magnetic resonance imaging (MRI) among medical imaging techniques, basic properties; basics of magnetic resonance (MR): relaxation, coordinate systems, Bloch equitations; impulse MR, spin echo; Fourier transformation (FT) and discrete FT; NMR spectroscopy; basic idea of MRI, one dimensional imaging; three dimensional imaging, frequency and phase coding; displaying the MRI image, resolution and field of view; basic imaging techniques and sequences; the contrast; imaging artifacts; special imaging techniques, advanced sequences; clinical applications of various sequences; the MRI hardware; safety and environmental issues.

Literature: C Westbrook, CK Roth, J Talbot: MRI in Practice (3rd edition) Wiley-Blackwell, ISBN-13: 978-1405127875

Nuclear medicine (2/0/1/e/4)
Responsible lecturer: Czirfus Szabolcs

Objective: to teach students the physical concepts related to nuclear medicine, the nuclear measurement technology issues and the basic ideas related to PET/SPECT technology and operation. Detailed curriculum of the subject**:** A brief summary of the methods of nuclear medicine, comprising the most important historical aspects. Summary of related nuclear phenomena and interaction types. Operating principle of the Anger camera, scintillating materials, photomultipliers, collimation techniques, implementations of the Anger camera, collimation techniques. Isotope diagnostics of plain image type: types of sources, efficiency, achievable image parameters, sources of noise, goals of examination. Principles of SPECT, methods of implementation, factors influencing the image quality and directions of application. Principles of PET, methods of implementation, factors influencing the image quality and directions of application. Production of isotopes needed for PET applications in accelerators, measurement and preparation of the isotopes for use. Possibilities to combine SPECT or PET with CT, advantages, achievable image parameters. Image reconstruction methods, their applicability, advantages and disadvantages. Modelling of PET/SPECT devices using the Monte Carlo method. Monitoring patient dose. Radiation protection in nuclear medicine, emergency procedures.

Literature: MN Wernick and JN Aarsvold, Emission Tomography: The Fundamentals of PET and SPECT. Elsevier 2004; DL Bailey et al. Positron Emission Tomography. Springer-Verlag London Limited 2005.

Medical imaging (3/1/0/e/4)
Responsible lecturer: Légrády Dávid

Objective: to teach the mathematical basis for medical image reconstruction.

Detailed curriculum of the subject: the concept of image, mathematical description of images, image quality concepts (contrast, geometrical resolution, noise, quantum efficiency, signal/noise ratio, MTF), medical imaging techniques with transmission, emission and induced emission, brief description of modalities (CT. Ultrasound, MRI, PET, SPECT), simulation of radiation, physical and mathematical modelling, mathematical and physical phantoms, linear systems. Fourier transform in image processing, the Radon transform, 2D filtered backprojection, 3D tomography. Iterative reconstruction methods (ML-EM, OSEM), Correction factors, practice of tomographical applications. Multimodal systems, segmentation, registration. Medical informatics, DICOM format

Literature: Frank Natterer, Frank Wübbeling, Mathematical Methods in Image Reconstruction (Monographs on Mathematical Modeling and Computation), SIAM, 2001, B Bendriem, DW Townsend: The Theory and practice of 3d pet, Springer 1998.

Physical foundations of X-ray diagnostics (2/1/0/e/4)
Responsible lecturer: Szalóki Imre

Basic interactions of X-rays with matter: photoelectric effect, coherent scattering, Compton-effect, reflection of X-rays, polarization, Bremsstrahlung, pair production, absorption. X-ray sources: X-ray tube, X-ray generator, radioactive isotopes, and synchrotron. X-ray detectors: film, fluorescent screen, gaseous detectors, scintillation and semiconductor detectors, pixelated detectors, cryogenic detectors. Technical parameters of X-ray detectors: efficiency, response function, dead time, coincidence. Absorption of X-rays, filters, elements of X-ray optics. Imaging in radiology: magnification, noise and scattering, contrast, lateral resolution, artefacts. Dual energy X-ray absorptiometry. Basic measuring geometries for computer tomography: parallel and cone-beam geometry. Mechanics of CT, detectors, collimation, filtering. Reconstruction methods: mathematical basis, projection slice-theorem, filtering projection, filtering back projection, algebraic reconstructions, spatial and contrast resolution, errors of projection and reconstruction. Reflection tomography, reconstruction methods of parallel and fan beam techniques. Medical applications of CT: computer tomography angiography, whole body CT, mammography, dental applications. Basic elements of dosimetry, application of dosimetry in X-ray diagnostic. Biological effects of X-rays, radiation protection, quality assurance.

Literature: A.C. Kak, M. Slaney, Principles of Computerized Tomographic Imaging, Electronic Copy (c) 1999, New York;