PhD18-22

The courses of the Doctoral School of PHYSICS at University of Debrecen, Hungary

2018.

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Debrecen, December 2018.

I. Atomic- and molecular physics program

Name of the teacher: **Dr. Ágnes Vibók** **PF1/31-93**

Atomic Physics

The goal of this course is to introduce the students to theoretical atomic physics. this course provides the basis to advanced special courses in atomic and molecular physics.

The structure of the course:

I. One-electron atoms
1. The Schrödinger-equation of one-electron atoms. Energy levels. The eigenfunctions of bound and continuum states.
2. Expectation values. The virial theorem.
3. Special hydrogen systems: muonium; positronium, hadronic atoms; Rydberg atoms

II. Interaction of one electron atoms with electromagnetic radiation
4. The electromagnetic field and its interaction with charged particles. Transition rates. The dipole approximation.
5. The Einstein-coefficients. Selection rules. Line intensities and lifetimes. Line shapes and widths.
6. Fine structure. The Zeeman-effect. The Stark-effect. The Lamb-shift

III. Two-electron atoms
7. The Schrödinger-equation for two-electron atoms, level scheme. The independent particle model.
8. The ground state, excited states and doubly excited states of two-electron atoms. Auger-effect.

IV. Many-electron atoms
9. The central field approximation. The Thomas-Fermi model.
10. The Hartree-Fock method and the self-consistent field. LS coupling and j-j coupling.
11. The interaction of many-electron atoms with electromagnetic fields

V. Atomic collisions
12. Basic principles and potential scattering

References:

1. B. H. Brandsden and C. J. Joachain, Physics of Atoms and Molecules, Longman Scientific & Technical, England, 1988
2. H.A. Bethe and E.E. Salpeter, Quantum Mechanics of One- and Two-Electron Atoms, Plenum Rosetta, New York, 1977
3. H. Friedrich, Theoretical Atomic Physics, Springer-Verlag, 1990

Name of the teacher: **Dr. Ágnes Vibók** **PF1/32-93**

Atomic and Molecular Physics

Some fundamental properties of atoms. Atomic structure and spectra. The hydrogen molecule. Diatomic molecules. Polyatomic molecules. Molecular orbital theory for □-electron systems. Electronic dipole moments. Magnetic susceptibilities. Vibration-Rotation spectra of diatomic and polyatomic molecules. Molecular electronic spectra.

References:
1. Weissbluth, M.: Atoms and molecules. (Academic Press, 1978)
2. Morrison, M. A.-Estll, T. L.-Lane, N. F.: Quantum states of atoms, molecules, and solids. (Pentice-Hall, Inc., Englewood Cliffs, New Jersey, 1976)
3. Herzberg, G.: Spectra of Diatomic Molecules (Van Nostrand-Reinhold, Princeton, New Jersey, 1950)
4. Herzberg, G.: Electronic Spectra and Electronic structure of polyatomic molecules. (Van Nostrand-Reinhold, Princeton, New Jersey, 1966)
5. Kapuy, E. Török F.: Az atomok és molekulák kvantumelmélete. (Akadémiai Kiadó, Budapest, 1975)

Name of the teachers: **Dr. László Sarkadi** **PF1/34-93**

Theory of Atomic Collisions

The goal of this course is to summarise the theoretical principles and techniques of modern atomic collision physics. The course will give the students a guided introduction to the literature of modern theories of atomic collision physics, and make the students capable to start theoretical work on a special field. For students in experimental atomic physics this course will give general guidance in atomic collision theory.

The structure of the course:

1.&2. Basic principles of scattering theory
3. Born approximation and semiclassical approximation
4.&5. Treatment of the long-range Coulomb force (SPB, CDW,etc.)
6. Photo-ionisation
7. Electron impact ionisation
8. Ionisation by heavy particle impact
9. Double and multiple ionisation
10. Recombination processes
11. Rearrangement processes
12. Electron correlation

References:
1. M. R. C. McDowell and J. P. Coleman, Introduction to the Theory of Ion-Atom
2. B. H. Brandsden and C. J. Joachain, Physics of Atoms and Molecules, Longman Scientific & Technical, England, 1988

3. B. H. Brandsden and M. R. C. McDowell, Charge Exchange and the Theory of Ion-Atom Collisions, Oxford Univ. Press (Int. Series of Monographs on Physics No.82.) Clarendon Press, 1992
4. H. Friedrich, Theoretical Atomic Physics, Springer-Verlag, 1990
5. Selected topics from D. Bates ed., Advances in Atomic and Molecular Physics, Academic Press, New York Vol. 1-30.

Name of the teachers: **Dr. József Pálinkás and Dr. László Sarkadi** **PF1/35-93**

Experimental Atomic Collision Physics

The goal of this course is to summarise the principles and techniques of modern experimental atomic collision physics. The course will give the students a guided introduction to the literature of modern experimental atomic collision physics, and make the students capable to start experimental work on a special field. For students in theoretical atomic physics this course will give general guidance in atomic collision experiments.

The structure of the course:

1&2. Preparation ion beams (ion sources, accelerators, storage rings)
3. Preparation of targets of solid and gaseous materials
4. X-ray sources (x-ray tubes, synchrotron radiation)
5&6. Experimental identification of basic collision processes (ionisation, charge exchange multielectron processes)
7. Rearrangement processes and their experimental identification (Auger, x-ray and Coster-Kronig processes, recombination)
8. X-ray spectrometers and detectors
9. Electron spectrometers and detectors
10. Coincidence techniques
11. Data reduction and analysis (analysis of X-ray and electron spectra, handling of coincidence data)
12. Recombination processes (RTE, DR, electron correlation)

References:
1. H. Haken and H. C. Wolf, Atomic and Quantum Physics, Springer-Verlag, 1991
2. Selected topics from C. Marton Editor-in-Chief, Methods of Experimental Physics, Academic Press, New York
3. Selected topics from D. Bates ed., Advances in Atomic and Molecular Physics, Academic Press, New York, Vol. 1-30.

Name of the teacher: **Dr. Zsolt Gulácsi** **PF1/37-93**

Many-Body Calculation Techniques and Applications

Green functions at $T = 0$ and $T \neq 0$ temperatures. Wick theorem. Gell Mann Low theorem. Feynmann diagrams. Correlation functions. The Matzubara technique. The Zubarev technique. The Gorkov equations. Canonical transformation. Applications (The BCS theory, Superfluidity, The Anderson model, Itinerant ferromagnetism, Description of coexistence problems, The Hubbard model, The periodic Anderson model, Description of two-band systems, excitonic systems, excitonic ferromagnet. Systems with localised spins, The Holstein-Primakoff transformations, The Edwards-Anderson model.)

References:
1. Fetter, A. L.-Walecka, J. D.: Quantum Theory of Many-Particle Systems. (McGraw-Hill Book Co., 1971)
2. Abrikosov, A. A.-Gorkov, L. P.-Dzyaloshinskii, I. Y.: Quantum Field Theoretical Methods in Statistical Physics (Pergamon Press, Second Ed., 1965)

Name of the teacher: **Dr. Ágnes Nagy** **PF1/39-93**

Density Functional Theory

Hohenberg-Kohn theorems, Slater-Gáspár-Kohn-Sham theory, free-electron gas approximation, Thomas-Fermi and related models, local density approximations, X□ method, chemical potential and electronegativity, extension to finite temperature, excited states, time dependent systems, relativistic electron density theory.

References:
1. Parr, R. G.-Yang, W.: Density Functional Theory of Atoms and Molecules. (Oxford Univ. Press, new York, 1989)
2. March, N. H.: Electron density theory of atoms and molecules. (Academic Press, London, 1992)
3. Lundgvist, S.-March, N. H.: Theory of the Inhomogeneous electron Gas. (Plenum Press, New York, 1983)
4. Erdahl, R., Smith, V. H.: Density Matrices and Density Functionals. (Reidel, Dordrecht, 1987)
5. Dreizler, R. M. Providencia, J.: Density functional Methods in Physics. (Plenum Press, New York,1985)
6. Keller, J.-Gázquez, J. I.: Density functional Theory, (Springer-Verlag, Berlin, 1983)

Name of the teacher: **Dr. Ágnes Nagy** **PF1/315-93**

Non-linear Phenomena, Chaos

Basic concept of non-linear dynamics. Hamiltonian and dissipative systems. Stability analysis. Poincaré map. Bifurcations. Logistic map. Chaotic motion. Fractals. Multifractals. Information, dimension, entropy. KAM theorem.

References:

1. Szépfalussy, P.-Tél, T.: Káosz (Akadémiai Kiadó, Budapest 1982)
2. Thompson, J. M. T.-Stewart, H. B.: Non-linear Dynamics and Chaos. (John Willey, New York 1986)

3. Lichtenberg, A. J.-Lieberman, M. A.: Regular and Stochastic Motion (Springer-Verlag New York, 1983)
4. Haken, I. I.: Szinergetika, (Mûszaki K., Budapest 1984)

Name of the teacher: **Dr. József Cseh** **PF1/319-97**

Symmetries in Two-Body and Many-Body Systems

(Same as PF2/32-93)

Name of the teacher: **Dr. Ágnes Nagy** **PF1/321-00**

Quantum Mechanics of Classical Chaotic Systems (Quantum Chaos)

Semiclassical (Einstein-Brillouin-Keller) quantization. Heron-Heiles coupled oscillators. Time reversal. Level repulsion. Random Matrix Theory. H-atom in magnetic field. Standard mapping.

Name of the teacher: **Dr. Károly Tőkési** **PF1/322-08**

Computational Simulation of Phenomena in Physics

Syllabus:
Introduction to the basics (2x2 lectures)
Mathematical description of physical systems, Monte Carlo methods (2x2 lectures)
Application in atomic physics, classical atom-models, the Kepler equation, 3-body systems (4x2 lectures)
Electrons Monte Carlo simulations in solid-state materials (2x2 lectures)
Higher order motions (4x2 lectures)

Literature:
Landau-Lifsic I Mechhanika
Bjarne Stroustroup: A C++ programozási nyelv (Kiskapu kiadó, 2001)
Jasmin Blanchette, Mark Summerfield: C++ CUI Programming with Qt 3
Thomas H. cormen, Charles E. Leiserson, Ronald L. Rivest: Algoritmusok (Műszaki kiadó, 1997)
Stoyan Gisbert, Takó Galina: Numerikus módszerek I. (Typotex, 2002)
Dunald E. Knuth: A számítógép-programozás művészete 3.

Name of the teacher: **Dr. Károly Tőkési** **PF1/323-08**

Basic examples in Programming

Syllabus:
Basics in software design (2x2 lectures)
Software design, algorithm, code (2x2 lectures)

3D simulation of elastic and inelastic collisions (4x2 lectures)
Complex description of the interaction of highly charged ions with surfaces (4x2 lectures)
Applications in nanophysics (6x2 lectures)

Literature:
Bjarne Stroustroup: A C++ programozási nyelv (Kiskapu kiadó, 2001)
John Vlissides, Richard Helm, Ralph Johnson, Erich Gamma: Programtervezési minták (kiskapu kiadó, 2004)
Jasmin Blanchette, Mark Summerfield: C++ CUI Programming with Qt 3
Bányász Gábor, Levendovszky Tihamér: Linux programozás (SZAK kiadó, 2003)
(a Qt-hez további dokumentáció)
Thomas H. cormen, Charles E. Leiserson, Ronald L. Rivest: Algoritmusok (Műszaki kiadó, 1997)
Numerical Recipies
Stoyan Gisbert, Takó Galina: Numerikus módszerek I. (Typotex, 2002)
Dunald E. Knuth: A számítógép-programozás művészete 3.

Name of the teacher: **Dr. Károly Tőkési** **PF1/325-14**

Introduction to the theory of attophysics

The course is held by Prof. Joachim Burgdörfer in English.

Topics:
1) Brief review: quantum dynamics in the time domain.
2) Classical-quantum correspondence and ultrashort time scales.
3) Time scales in atoms, molecular, and condensed matter physics.
4) Excursion: experimental progress towards time-resolving ultrafast processes.
5) Elements of "strong-field " physics.
6) Time and time delay operator.
7) Attosecond streaking and related processes.
8) Applications of streaking to atoms, molecules, and solids.
9) Quantum time ordering operator as observable.
10) The "tunneling time" controversy: can attophysics contribute to its resolution?
11) Combining atto with nano: subcycle resolved emission from nanostructures.
12) Towards light field electronics: (sub)femto second insulator -to- metal transition.

Name of the teacher: **Dr. Róbert Erdélyi** **PF1/326-18**

Introduction to Plasmaphysics

(*Same as* **PF4/324-18**)

II. Nuclear Physics program

Name of the teachers: **Dr. István Angeli, Dr. Barna Nyakó** **PF2/31-93**

Charge and Mass Distributions of Atomic Nuclei

Methods of measuring nuclear charge distributions: problems and corrections relating to data evaluation. Model functions and model independent characteristics of charge distributions. Fine structure in the mass number dependence of charge radii; correlation with the fine structure of binding energy. Radius formulae. Measuring methods of the nucleon distributions. Role of the nuclear surface. Measurement and interpretation of fast neutron cross sections. The optical model(s).

Investigation of nuclear deformation by electromagnetic and nuclear interactions; deformation parameters. Special shapes of nuclei: superdeformed, triaxial, octupole; shape co-existence. Formation of superdeformed nuclei and the experimental investigation of their decay; general tendencies in the results. Search for hyperdeformed nuclei.

References:
1. C. J. Batty, et al.: Advances in Nuclear Physics, 19 (1989) 1
2. J. F. Sharpey-Schafer, and J. Simpson: Progress in Particle and Nuclear Physics, 21 (1988) 293

Name of the teacher: **Dr. József Cseh** **PF2/32-93**

Symmetries in Two-Body and Many-Body Systems

Content:
I. Applications of compact unitary algebras

$U(2)$: angular momentum
isospin
vibrations of two-atomic molecules

$U(3)$: strangeness and quarks
three-dimensional harmonic oscillator
shell model and Elliot model of atomic nuclei

$U(4)$: rotation-vibration of two-atomic molecules
Wigner's supermultiplets, nuclear mass
simple cluster model of atomic nuclei
meson spectrum
$U_1(4)$ Ä...Ä$U_{k-1}(4)$: rotation-vibration of *k*-atomic molecules
$U(4)$ Ä $U^{ST}(4)$ Ä $U(3)$...: cluster model of nuclei

$U(6)$: collective states in nuclei
chaos and dynamical symmetry
hypernuclei
flavour-spin symmetry in the spectrum of hadrons
$U(6)$ Ä $U(\mathrm{m})$: collective and single-particle states of nuclei

$U(7)$: three-body problem in quantum mechanics
triatomic molecules
alpha-cluster states of atomic nuclei

barionspectrum

II. Applications of other algebras:

$O(4)$:	symmetry of the Kepler problem
$O(3,1)$:	algebraic scattering theory
$O(4,2)$:	dynamical algebra of the Kepler problem
$U(6/m)$:	supersymmetry in nuclei
$U_q(m)$:	quantum groups in many-body theory

Name of the teachers: **Dr. Borbála Gyarmati, Dr. Tamás Vertse** **PF2/35-93**

Nuclear Models

Programme:
I. semester

1. The liquid drop model (2 lectures)
2. The shell model (3 lectures)
3. Rotation and single-particle motion (2 lectures)
4. Nuclear forces (2 lectures)
5. The Hartree - Fock method (2 lectures)

II. semester

6. Pairing correlations and superfluid nuclei (2 lectures)
7. The generalised single-particle model (2 lectures)
8. Harmonic vibrations (2 lectures)
9. the nuclear cluster model (2 lectures)
10. The time dependent Hartree - Fock method (2 lectures)

Name of the teachers: **Dr. Endre Somorjai** **PF2/36-93**

Nuclear Astrophysics

A.) General properties of stars (Observable quantities)
Luminosity; temperature; mass; radius; distance.
Energetics. The Hertzsprung-Russell diagram.
Stellar population. Stellar evolution. Physical description of the stellar interior.

B.) Explanation of the Universe
Cosmology (big bang). Nucleogenesis in the early Universe. The formation of Galaxies. Cosmic background radiation. Cosmology and elementary particles.

C.) General characteristics of thermonuclear reactions
Source of nuclear energy. Cross section, stellar reaction rate. Cross section factor. Energy production. Determination of different stellar reaction rates.

D.) Processes of energy production and/or nucleosynthesis.
Hydrogen-burning (p-p chains, CNO and other cycles). Helium-burning. Advanced (C,Ne,O and Si) and explosive (Supernovae) burning.
The s-, r-, and p-processes.

E.) Laboratory equipment and techniques in nuclear astrophysics
Ion beams (ion-sources, accelerators). Target features and target chambers. Detectors and detection techniques. Experimental procedures and data reduction. Future techniques (radioactive ions/targets, etc.)

F. Miscellaneous topics
The solar-neutrino problem. Isotopic anomalies and their interpretation. The origin of the light elements (galactic cosmic rays, spallation reactions).

Name of the teacher: **Dr. Tamás Lakatos and Dr. János Gál** **PF2/37-93**

Electronic Measurement of Physical Quantities

(Same as PF1/36-93)

Name of the teacher: **Dr. István Lovas** **PF2/38-93**

Particle Physics

1. The classification of particles
2. The classification of the fundamental interactions
3. The discovery of the "elementary" particles
4. Symmetries and conservation laws
5. The quark model of the hadrons
6. Gauge theories
7. The strong interaction
8. The electron-weak interaction
9. High energy scattering experiments
10. The grand unified theories
11. Introduction to the cosmology
12. Open questions of particle physics

Name of the teacher: **Dr. Sándor Nagy** **PF2/310-93**

Nuclear Fission

Basic description of the fission process. Spontaneous and induced fission. Main properties of low-energy fission (mass-, charge-, angular- and kinetic energy-distributions of fission fragments and products, emission of prompt neutrons and gamma-quanta, their correlation). Description of the fission process by different models. Cold fission. Experimental methods and instruments used in the study of nuclear fission.

Name of the teacher: **Dr. Sándor Nagy** **PF2/311-93**

Methods and Practice of Gamma-Spectrometry

Gamma-spectrometers and their components (detectors and electronics). Source-detector arrangements, collimators, shielding. Calibration of spectrometers (energy, efficiency). Methods and practice of spectrum evaluation. Corrections. Computer programs for gamma-spectrum evaluation and radionuclide analysis. Special detector systems. Examples for the application of gamma-spectrometry.

References:
1. K. Debertin, R. G. Helmer: Gamma and X-ray spectrometry with semiconductor detectors (North-Holland,) Amsterdam, 1988).

Name of the teachers: **Dr. Péter Raics and Dr. Sándor Sudár** **PF2/312-93**

Methods for the Analysis of Nuclear Reactions

Experimental data for the description of the reactions. Production and diagnostic of charged particle beams. Neutron sources, characterisation of neutron fields (flux density, background). Detection and spectrometry of the reaction products. Cross section measurements: activation technique, prompt methods. Determination of excitation functions. Measurements of differential cross sections. Correlation techniques, multi-parameter measurements.

Introduction to the theory of elastic and inelastic scattering and nuclear reactions, direct and compound reactions. Optical model, coupled channels calculations, scattering matrices. Statistical models of the nuclear reactions: Hauser-Feshbach model, preequlibrium models (exciton, geometry dependent hybrid model, etc.) Multistep direct and compound reactions. Survey of nuclear reaction model computer codes. Nuclear reaction models in the evaluation procedure.

The lectures are completed with practical work.

Name of the teacher: **Dr. Kornél Sailer** **PF2/313-93**

Non-Equilibrium Statistical Physics

Principle of maximum missing information. Entropy with respect to a sufficient observation level. First and second law of dynamical processes. Generalised canonical statistical operator for dynamic processes. Relevant and irrelevant physical observables. Relevant and irrelevant parts of the statistical operator. Linear response theory. Small deviations from equilibrium. Nakajima-Zwanzig- and Robertson equations.

Name of the teacher: **Dr. Kornél Sailer** **PF2/314-93**

TRIANGLE-Course

Intensive postgraduate courses (one week) in any 2-3 years, organised in the framework of TRIANGLE in middle-European co-operation (Eötvös University, Budapest; Comenius University, Bratislava; University of Vienna) by inviting Hungarian and foreign experts of some topics in the front of recent developments of nuclear physics.

Name of the teacher: **Dr. Kornél Sailer** **PF2/315-93**

Introduction to Quantum Field Theory

Feynman's path integral. Generating functional of quantum field theory. Green's functions. Perturbation theory. Feynman rules. *S*-matrix and differential cross sections. Global symmetries in field theory. Conserved currents (Noether-theorem) Local gauge symmetries. Path integral quantization of gauge theories (Faddeev-Popov method, ghost fields). Differential cross section of Compton-scattering.

Name of the teacher: **Dr. Kornél Sailer** **PF2/317-93**

Symmetries and Symmetry Breaking in Quantum Field Theory

Gauge theories and BRS symmetry. Regularisation methods in quantum field theory. Renormalization group symmetry. Scaling symmetry. Dimensional transmutation. Ward- and Slavnov-Taylor identities. Explicit, spontaneous and anomalous breaking of symmetries. Spontaneous breaking of global and local symmetries. Goldstone-boson. Higgs-mechanism. Pion, as Goldstone-boson. Higgs-mechanism in the theory of electro-weak interaction. Chiral symmetry and anomaly in low-energy hadron physics. Centre symmetry in QCD and confinement. Dynamical breaking of centre symmetry.

Name of the teacher: **Dr. László Végh** **PF2/318-93**

Advanced Quantum Mechanics

(Same as PF1/316-93)

Name of the teacher: **Dr. László Zolnai** **PF2/320-93**

Angular Distribution Measurement of the Elastically Scattered Alpha Particles

(Form: exercise, 5x6 hours)

Programme:

1. Target preparation
   - Preparation of the Au/Ni target by vacuum evaporation
   - Use of the vacuum evaporation equipment
2. Thickness measurement by alpha-source
   - Measurement of the energy spectrum
   - Derivation of the target thickness from energy shift

3/a. Checking of the Rutherford-formulae
   - Measurement of the alpha angular distribution, on the beam of the Van de Graaff accelerator at 1 MeV

- Evaluation of the measured data

3/b. Determination of the optical model potential
- Measurement of the alpha angular distribution, on the beam of the cyclotron at 20MeV
- Evaluation of the measured data
- Derivation of the optical model potential

Name of the teacher: **Dr. Zoltán Trócsányi** **PF2/321-94**

Standard Model

We discuss the phenomenology of electroweak and strong interactions by deriving it from the *SU*(3)x*SU*(2)x*U*(1) gauge theory. We begin with a brief review of symmetries in field theory. Then we plunge into a description of the standard *SU*(3)x*SU*(2)x*U*(1) gauge theory.

The main chapters are:

- *SU*(2)x*U*(1) and leptons
- quarks and colour *SU*(3)
- perturbative QCD
- semileptonic decays of hadrons
- chiral Lagrangians
- renormalization of the Standard Model

Name of the teacher: **Dr. Kornél Sailer** **PF2/322-93**

String Theory

The classical bosonic string. The quantised bosonic string. Conform field theory. Reparametrization ghosts and BRST quantization. The classical closed fermionic string. Quantization of the closed fermionic string. Super strings. 10-dimensional heterotic string. Kac-Moody algebras. Covariant lattices. Heterotic strings in 4 dimensions. Low energy theory.

Name of the teacher: **Dr. Attila Krasznahorkay** **PF2/323-93**

Measurements with Magnetic Spectrograph

(Laboratory experiments, 5x6 h)

Subject:

1./ Getting acquainted with the magnetic spectrograph and using of it working principle b□ values, double focusing, energy resolution, solid angle

- Magnetic field measurements with NMR
- Position sensitive Si detectors

2./ Alpha particle angular distribution measurements with the magnetic spectrograph in the $^{154}Sm(a,a')$ reaction at E_a=10 and 18 MeV

3./ Data reduction and discussion of the results. Determination of the mass quadrupole deformation parameter of ^{154}Sm

Name of the teacher: **Dr. Julius Csikai** **PF2/324-95**

Neutron and Reactor Physics

Physical properties of the neutron. Neutron sources. Neutron detectors. Slowing down and diffusion of neutrons. Determination of energy spectrum and flux density of neutrons. Neutron induced reactions. Measurement of cross sections. Optical properties of neutrons and their applications. Nuclear fission. Critical systems. Heterogeneous reactors. Homogeneous reactors. Reactor kinetics and control.

Name of the teacher: **Dr. Julius Csikai** **PF2/325-95**

Application of Nuclear Methods in Science and Technology

Destructive and non destructive analytical methods. Principles and techniques used in structure studies of condensed matter. Determinations of microscopic and macroscopic physical parameters of samples of different dimensions and compositions. Radiation effects in different technological and biological materials. A comparison of sensitivity and accuracy of analytical methods. Advantages and limitations of nuclear methods.

Name of the teacher: **Dr. Julius Csikai** **PF2/326-95**

Radioactivity and Nuclear Physics

Radioactivity. The radioactive decay law. Alpha, beta and gamma-decay, electron capture. Interactions of radiations with matter. Radiation detectors. Static and dynamical properties of the nucleus. Elementary particles and fundamental interactions. Development of the Universe. Particle accelerators.

Name of the teacher: **Dr. Sailer Kornél** **PF2/327-95**

Finite Temperature Quantum Field Theory

Ideal Fermi- and Bose-gas. Interacting fields (perturbative treatment). Finite temperature Quantum electrodynamics (blackbody radiation, electron-positron plasma) finite temperature Quantum Chromodynamics (quark-gluon plasma). Phase transitions.

Name of the teacher: **Dr. Sailer Kornél** **PF2/328-96**

Renormalization Group Methods in Physics

Self-similarity and scale invariance. Renormalization group approach to chaos, percolation and critical phenomena. Scalar field theory: mean field approximation, spontaneous symmetry breaking, Gaussian fixed point. Wegner-Houghton-equation. e-expansion. Kosterlitz-Thouless phase transition.

Name of the teacher: **Dr. Tamás Vertse** **PF2/329-97**

Numerical Methods in Practice

The purpose of the course is to make students familiar with the solution of the most common numerical problems through practical programming in FORTRAN. The students will work interactively on the terminals of the VAX-6000 computer of the Computer Centre of the University.

Main subjects:

1. interpolation,
2. numerical differentation and quadrature,
3. solution of differential equations,
4. solution of linear equation systems,
5. eigenvalue problems,
6. nonlinear equations and systems of nonlinear equations,
7. approximations by functions.

Name of the teacher: **Dr. József Cseh** **PF2/330-97**

Seminars on Nuclear Physics

This series of seminars gives an insight into the present day nuclear research. It consists of two parts. On the one hand side, there are lectures in every second week (in the average), delivered either by local experts (from the KLTE or ATOMKI), or by the visiting scientists. On the other hand side, it includes short talks by the students, based on review articles on the most recent issues in nuclear research.

Name of the teacher: **Dr. Zoltán Papp** **PF2/331-97**

Quantum Mechanical Few-Body Problem

Contents:

- formal scattering theory; solution methods
- few-body equations
- Faddeev equations; solution methods

Faddeev equations with Coulomb potential; solution methods

Name of the teacher: **Dr. László Zolnai** **PF2/332-93**

Sciencetechnology

Introduction. Organisation of the University of Debrecen, Hungarian Academy of Sciences and Institute of Nuclear Research. Who is who at the university and at the INR. Administration at the campus - Basic concepts of the organisation of the research. Searching the scientific literature. Use of the tools of information technique. Use of the Science Citation Index (SCI). Collection and reporting of the publications and citations. Use of the World Wide Web. Local possibilities. - Informal communication, collaborations, Questions and criticism. - Formal communication: Technique of talks, posters and speaches. Writing papers, applications, reports. - Scientometrics, Basic concepts. - Evaluational methods and criteria of the research, pecularities in Hungary: Accreditation of the universities, evaluation at the HAS. A case study: INR. - Self-evaluation and behaviour. - Time allocation and self-assesment. - Looking for jobs, writing CV-s.

Name of the teacher: **Dr. Rezső Lovas** **PF2/333-01**

(Structure and Reactions of) Light Exotic Nuclei

The course spans two semesters, and can be considered two independent subjects. It can be delivered as a two-semester lecture course of two hours per week or it can be worked through as a series of consultations based on the students private reading prior to each consultation class. The course is based on the book entitled Structure and Reactions of Light Exotic Nuclei to be published, which can be passed to the students in an electronic form. The lectures may be delivered in Hungarian or English at request.

The atomic nuclei whose proton-neutron composition substantially differs from what is usual in their mass number region are called exotic.

Owing to their unusual composition and to their few nucleons, the light exotic nuclei are out of the range of validity of the traditional nuclear models. In particular the independent-particle picture loses its validity for them. Their nucleons tend to group into clusters and their dynamics consists in the relative motion of the clusters and of the nonclustered nucleons, thus it is essentially few-body dynamics. The most exotic examples are the neutron-halo nuclei (e.g., ^{6}He or ^{11}Li).

The life-times of these nuclei are very short. They have been accessible to experimental studies since the mid-80’s, when it became possible to produce accelerated beams of the ions of such nuclei, and make them collide with stable targets. The theory of their reactions is based on the eikonal approximation. Their structure can be visualized by various models. The course will treat their problem in the correlated Gaussion approach.

Synopsis

Structure of Light Exotic Nuclei

1. Introduction. The inadequacy of the mean-field and shell-model descriptions
2. Correlated Gaussian basis I. Variational trial function
3. Correlated Gaussian basis II. The generating function of the problem
4. Correlated Gaussian basis III. Calculation of the matrix elements
5. Stochastic variational method

6. The description of discrete unbound states
7. Measurement of clustering
8. Fundamentals of the cluster models
9. The resonating-group method and the generator coordinate method
10. Macroscopic description on microscopic grunds
11. Correlated Gaussian cluster model
12. A full example: the ssix-nucleon system (^{6}He, ^{6}Li)
13. Review of nuclei of mass numbers 5-11

Reactions of Light Exotic Nuclei

1. Fundamentals of scattering theory
2. Potential scattering in eikonal approximation: theory
3. Potential scattering in eikonal approximation: applications
4. Glauber theory of the collisions of composite nuclei
5. The optical-limit approximation
6. High-energy (~1 GeV per nucleon) reactions of neutron-halo nuclei
7. Medium-energy (~100 MeV per nucleon) reactions of neutron-halo nuclei
8. Momentum distribution of the fragments
9. Goulomb breakup of neutron-halo nuclei: theory
10. Coulomb breakup of neutron-halo nuclei: applications
11. Reaction calculations based on microscopic structure calculations
12. Review of our knowledge on light exotic nuclei

Name of the teachers: **Dr. Kornél Sailer, Dr. Zsolt Schram** **PF2/334-02**

Models and Methods in Theoretical Physics

Teaching staff of University of Debrecen, and invited lecturers from Hungary and abroad are presenting weekly seminars on actual problems and new results in theoretical physics. The lectures, concentrating on principial and technical aspects, are describing new models, new procedures and methods, and new developments in computational physics.

Name of the teacher: **Dr. Attila Krasznahorkay** **PF2/335-06**

Experiments with magnetic mass separator

Installation of a radiofrequency type ion source and studying their characteristics. Acceleration of the ions by electrostatic field, observation of the beam spot on a quartz screen. Estimation of the beam emittance. Focusing with an electrostatic quadrupole lens.

Deflection of the beam in magnetic field. Measuring the field with a Hall probe and more precisely with NMR field meter. Calculation and measurement of the beam deflection. The effect of the magnetic deflection on the focusing properties of the beam. Measuring the beam current along the focal plane of the magnet. Searching for the different nitrogen and oxygen isotopes at the focal plane. Optimalization the mass resolution of the separator.

Implanting ^{15}N ions into steel surface. Measuring the depth distribution of ^{15}N with the ^{15}N(p,α γ)^{12}C nuclear reaction. Observation of the yield of the 4.44 MeV γ-radiation of ^{12}C around the E_p = 898 keV resonance.

Name of the teacher: **Dr. Attila Krasznahorkay** **PF2/336-10**

Collective excitations in atomic nuclei

- Discovery of low lying rotational and vibrational states in atomic nuclei and their theoretical description. Highly deformed, super- and hyperdeformed states.
- Discovery of the first giant resonances and their description with the liquid-drop model. Classification of giant resonances. Selective excitations with different nuclear reactions. Isoscalar and isovector giant resonances.
- Spin and isospin excitations. Microscopic description, sum rules. Experimental methods for the investigations. Decay of the giant resonances.
- Summary of the experimental results obtained for the properties of the giant resonances.
- Some applications of the giant resonances for constraining the parameters of the equation of state of the nuclear matter.

Name of the teacher: **Dr. János Timár** **PF2/337-11**

The rotating nucleus: an experimental view

The course intends to summarize fundamental knowledge on nuclear rotation, and on experimental techniques necessary to study nuclear rotation. It gives also an overview on some contemporary topics of nuclear rotation.

Content:

- The rotational band: concept, characteristic properties, and features in different types of nuclei.
- Experimental properties of rotational band: dipole and quadrupole band, rotational frequency, moment of inertia, Routhian, alignment, electromagnetic transition probabilities, lifetime, quadrupole moment.
- Relation between the experimentally measured properties and the intrinsic single-particle configurations.
- Experimental techniques: fusion-evaporation reaction, ball gamma-detector systems, ancillary detectors, manifold gamma-ray coincidences, DCO, linear polarization, level lifetime measurements.
- Special phenomena in nuclear rotation: band crossing, band termination, signature inversion, chiral rotation.

Name of the teacher: **Dr. Zsolt Fülöp** **PF2/338-12**

Introduction to Nuclear Astrophysics

The course is held by Prof. Thomas Rauscher in English.

Short repetition of thermodynamics and equation of state

Short introduction into nuclear reaction theory

Astrophysical reaction rates and reaction networks

Primordial nucleosynthesis (standard and non-standard)

Cosmic Microwave Background

Hydrostatic Burning Phases of Stars (nuclear aspects):

Hydrogen Burning (pp-chains, CNO cycles)

- short discussion of the solar neutrino problem
- Helium burning
- Late burning phases: C-, Ne-, O-, Si-burning

(Simple) Stellar models and stellar structure:

- Basic hydrostatic equations of stellar structure
- Lane-Emden equation
- Basic properties of white dwarfs
- The star as a mixture of gas and radiation
- Energy transport (overview)

Overview of stellar properties and evolution as a function of stellar mass:

- Brown dwarfs and the lightest stars
- AGB stars and their He-shell flashes (site of the main s-process)
- Massive stars
- Supermassive stars (above 30 solar masses)

Nucleosynthesis beyond Fe:

- s-process
- r-process
- p-process (gamma-process)
- (rp-process) (see also below)
- (■-p process) (see also below)

Explosive Environments:

- Explosive nucleosynthesis (general consideration)
  - Core-collapse Supernovae:

    - Explosion mechanism

    - Nucleosynthesis (deep layers (r-process, ■-p process), outer layers (explosive shell burning))
  - Binary Systems:

    - Accretion on the neutron star surface (X-ray bursts, rp-process)

    - Type Ia Supernovae :

      – Mechanism

      – Nucleosynthesis

      – Cosmological importance as distance measure

Name of the teacher: **Dr. Dezső Horváth** **PF2/339-12**

The Standard Model and its experimental tests

(See PF5/326-00)

Name of the teacher: **Dr. István Angeli** **PF2/340-13**

High Energy Accelerators I.-II.

(See PF5/31-95)

Name of the teacher: **Dr. Attila Krasznahorkay, Dr. Lóránt Csige** **PF2/341-14**

Modern nuclear instruments and methods

Innovations in detector technology: the structure of new scintillation (LaBr3), gas (GEM, THGEM, MICROMEGAS) and semiconductor detectors (DSSD strip detector), their operating principles, parameters, usage, advantages and disadvantages. Modern, complex detector systems, such as Bragg ionization chambers and TPC detectors. Digital signal processing techniques, noise cancellation and signal processing algorithms, the C ++ implementation of the algorihms, and their use of Root. Comparison of analogue and digital signal processing, their advantages and disadvantages.

Note:

The presentations are followed by a block of the labs (2x6 hours), during which test experiments will be performed in the Atomki cyclotron laboratory using the new types of detectors (eg, DSSD, THGEM and Bragg ionization chamber) presented in the lectures. The ionization chamber signals collected from performing digital signal processing with a CAEN 62.5 MS /s unit will also be compared to the performance of traditional analogue electronics. The advantages and disadvantages of the different digital signal processing algoritms will be discussed, with special attention to the particle identification methods.

Name of the teacher: **Dr. Zoltán Elekes** **PF2/342-14**

Exotic nuclear physics

Our experimental knowledge about the features of atomic nuclei and the interaction between the nucleons was mainly achieved by using stable ion beams. However, the focus of this kind of research has recently shifted towards the region of unstable nuclei. The investigations aims not only to uncover the structure of atomic nuclei but also to describe the behavior of celestial objects and to understand the abundance of elements in the Universe, since almost all the processes in question involve exotic nuclei. During the course the instrumental and methodological background of the experiments as well as the peculiar phenomena observed in the last twenty years will be presented. The following topics will be discussed:

1. basics of ion accelerators applied
2. methods for producing radioactive ion beams
3. working principles of isotope separators
4. identification of isotopes in the radioactive ion beams
5. basics of the beam detectors (e.g., trajectory determination, plastic scintillator, semiconductor detectors, ionization chambers)
6. basics of experimental methods (e.g., Coulomb exciation, inelastic proton scattering, direct reactions, invariant mass, g-spectroscopy)
7. identification and detection of reaction products (e.g., telescope, hodoscope, neutron and g arrays)
8. shell structure far away from stability, change of magic numbers
9. neutron skin, neutron halo
10. collective behaviour far away from stability, pygmy resonance
    effects of exotic phenomena to astrophysical processes

Name of the teacher: **Dr. Mihály Molnár** **PF2/343-14**

Meteorites, the Early Solar System and Nuclear Astrophysics

(*See* PF4/319-14)

Name of the teacher: **Dr. Róbert Erdélyi** **PF2/344-18**

Introduction to Plasmaphysics

(*See* **PF4/324-18**)

Name of the teacher: **Dr. Zsolt Fülöp** **PF2/345-18**

Neutrino Physics

The course is held by Dr. Kai Zuber in English.

- Introduction, History of neutrinos
- Neutrinos and their interaction
- Neutrino masses
- Neutrino oscillations (Reactors, Atmospheric)
- Astrophysical neutrinos (Sun, Supernovae, High energy neutrinos)
- Future and open questions of neutrino physics

Suggested reading: K. Zuber: Neutrino Physics, CRC Press 2011

III. Solid State Physics and Material Science program

Name of the teachers: **Dr. Dezső Beke** **PF3/31-93**

Solid State Physics

The of bonding (Madelung-constant). Similarity of the interatomic potentials (empirical-laws as consequences of the similarity, principles of the dimension analysis). Lattice vibrations (phonons, anelastic neutron scattering). Thermal properties (specific heat, thermal expansion, thermal conductivity, Mössbauer effect). Electron states (Bloch-states, band-structure, Fermi-energy, effective mass). Interpretation of the electrical resistivity (temperature-dependence, conductors, semiconductors, impurity-scattering). Thermo-electricity. Dielectric properties. Magnetic properties (para- dia- and ferro-magnetic materials). Superconductivity. Optical properties. Point defects (concentration of vacancies, interstitials and pairs of point defects, their migration). Atomic transport (diffusion, chemical diffusion, thermo- and electro-migration, creep). Regular solid solutions (ordering, miscibility-gap, solubility, surface segregation). Dislocations and their interactions (plasticity). Surface energy and its temperature dependence (equilibrium shape, surface defects, surface diffusion). Grain- and phase-boundaries (DSL and CSL, structural units, mismatch-possibilities, relaxations).

References:
1. C. Kittel: Introduction to solid state Physics, 5th edition, John Wiley and Sons., 1979
2. J. M. Ziman: Principles of the Theory of Solids, Cambridge, University Press, 1965
3. P. Sz. Kirijev: Félvezetõk fizikája, Tankönyvkiadó, Budapest, 1974
4. A. W. Harrison: Pseudo potentials in the Theory of Solids, North-Holland Publ. Co., Amsterdam, 1975
5. R. W. Cahn, P. Haasen: Physical Metallurgy, North-Holland, Amsterdam, 1983
6. J. Giber et al.: Szilárdtestek felületfizikája, Mûszaki Kiadó, Budapest

Name of the teacher: **Dr. Zsolt Gulácsi** **PF3/32-93**

Theoretical Solid State Physics

Fermi liquids, Bose liquids. The Luttinger liquid. Magnetic properties of localised systems. Magnetic properties if itinerant systems. Excitonic systems. Magnons. Phonons. Electron-Phonon interactions. Superconductivity. Impurities. Effect of impurities on condensed phases. Renormalization Groups and applications. Strongly correlated systems. Metal-insulator transitions, Heavy-Fermion systems. Spin-glasses. Quantum Hall Effect. Dynamical properties.

References:
1. Theory of Quantum liquids: D. Pines, P. Nozieres, W,A, Benjamin Inc., 1966
2. Quantum Field Theoretical Methods in Statistical Physics, A. A. Abrikosov, L. P. Gorkov, I. Y. Dzyaloshinskii Pergamon Press, 1965
3. Phase Transitions and Critical Phenomena, vol. 1-15. Ed. by C. Domb, M.S. Green, J. L. Lebowitz

Name of the teacher: **Dr. Dezső Beke** **PF3/33-93**

New Materials and Technologies

Amorphous, nano- and micro crystalline materials. Ceramics, composite materials, Sintering. Ion implantation. Nitrides, borides, carbides, silicides. Modern, surface investigation methods, analysis of tracer-elements, micro alloying. High T_c superconductors. Properties and preparation of thin films.

References:

1. R. W. Cahn, P. Haasen: Physical Metallurgy I-II., North-Holland, 1983
2. D. C. Van Aken, G. S. Was, Chosh (eds.), Micro composites and nanophase Materials, A Publication of TMS, Warrendale 1991.

Name of the teacher: **Dr. Zsolt Gulácsi** **PF3/35-93**

Phase Transitions and Renormalization Groups

The order of transitions; Fluctuations, correlations and dependence on dimensionality; The order parameter; Landau theory of phase transitions; Mean-field descriptions (localized spin systems, the van der Waals gas); Critical exponents; The Kadanoff construction and generalized homogenity; The static scaling, relations between critical exponents;The Kosterlitz-Thonless transition; Systems with frustration, the spin-glass phase; The renormalisation group; The Wilson recursion relation; Calculation of the critical exponents.

References:
1. Shang-Kend Ma: Modern Theory of Critical Phenomena, W.A. Benjamin Inc, 1976
2. Finn Ravndal: Scaling and Renormalisation Group Nordita, Copenhagen 1976
3. Phase Transition and Critical Phenomena, vol 1-15 Ed. By C. Domb, M. S. Green, J. L. Lebowitz, Academic Press
4. L. D. Landau, E. M. Lifsic, L. P. Pitajevskij, series Nauka, 1978

Name of the teacher: **Dr. Sándor Mészáros** **PF3/36-93**

Superconductivity

Electron motion in solids, collective charge transport. Basic properties of superconductors, macroscopic description of superconducting state, the London equations. The BCS theory and its application for classical superconductors. Possible mechanisms of superconductivity, exotic and high T_c superconductors. Structure and dynamics of magnetic vortex lattice, pinning. The Ginsburg-Landau theory. Superconductors in high frequency electromagnetic field. Weakly coupled superconductors, Josephson effects, macroscopic quantum phenomena.

References:
1. D. R. Tilley and J. Tilley, Superfluidity and Superconductivity, Van Nostrand Reinhold Co., 1974
2. H. Ehrenrhein and D. Turnbull, Solid State Physics, Academic Press, 1989

3. J. G. Bednorz and K. A. Müller (editors), Realier and Recent Aspects of Superconductivity, Springer Verlag, 1989
4. D. M. Ginsberg (editor), Physical Properties of High Temperature Superconductors, vol. I.,II.,III., World Scientific 1992
5. L. Solymar, Superconductive Tunneling and Applictions, Chapman and Hall, 1972
6. J. C. Gallop, SQUIDS, the Josephson Effects and Superconducting Electronics, Adam Hilger, 1991

Name of the teacher: **Dr. Sándor Mészáros** **PF3/37-93**

Modern Methods in Material Science and Analysis

Application of low temperature techniques and superconductive instrumentation in material science and analysis: superconducting magnets, NMR, SQUID-based instruments, residual resistivity measurements, SQUID magnetometers, alternative NMR technique.

References:
1. J. C. Gallop, SQUIDS, the Josephson Effects and Superconducting Electronics, Adam Hilger, 1991
2. J. G. Badnorz and K. A. Müller (editors), Realier and Recent Aspects of Superconductivity, Springer Verlag, 1989

Name of the teacher: **Dr. Gábor Erdélyi** **PF3/39-93**

Solid State Reactions

Thermodynamic functions of binary and ternary systems, phase diagrams. Classification of solid state reactions. Crystal defects in ionic crystals, oxides and compounds. Interdiffusion, morphology of the reaction products, growth kinetics of the new phases. Effects of high pressure. Metal-metal, metal-ceramic contacts, diffusion bonding. Multilayer structures, amorphisation by diffusion and mechanical deformations. High pressure induced amorphisation. Technologically important solid-state reactions: sintering, oxidation of metals, degradation of metals and ceramics at elevated temperatures.

References:
1. H. Schmelzried: Solid State reactions Verlag Chemie, Weinheim 1981
2. Chemical Thermodynamics of Materials C. H. P. Lupis, North-Holland 1983
3. Fundamentals of Diffusion Bonding Ed. Y. Ishida, Elsevier 1987
4. Proceedings of Int. Syms. on metal-ceramic interfaces, 1991 Acta Met. Suppl. 40, 1992

Name of the teachers: **Dr. László Kövér** **PF3/311-93**

Analysis of Solid Surfaces

Basic concepts: Surface phenomena (relaxation, reconstruction, development of surfaces and interfaces, surface reactions): properties of surfaces (surface structure, surface chemical composition, electronic and magnetic structure, dynamical properties): review and comparison of methods of surface analysis.

Experimental methods of surface and interface research: Introduction (physical basis of the methods, fundamental experimental conditions, exciting sources, analyses, depth profiling); methods of analysis of surface structures (diffraction methods: LEED, RHEED, photoelectron diffraction and holography; field emission methods: APFIM, STM, AFM, ion scattering -> ISS; X-ray absorption fine structure analysis: SEXAFS; analysis of surface morphology by spectromicroscopic methods); methods of analysis of surface composition, electronic and magnetic structure (electron spectroscopic methods: XPS, AES, UPS, EELS, HREELS; ion scattering and mass spectroscopic methods: ISS, SIMS, FABMS, RBS; desorption and optical methods: ESD, PSD, ellipsometry, GDOS; methods of determination of work function and contact potential); dynamical properties (analysis of surface lattice dynamics, methods of studies of surface diffusion and segregation, studies of excited states using laser induced methods).

Examples of applications and practical demonstration: possibilities and problems of quantitative analytical applications, 3 dimensional analysis of surface and interface layers, perspectives, application of surface analytical methods for studying surface reactions, corrosion, surface properties and structure of alloys, semiconductors, superconductor and polymers, visits to electron spectroscopic, mass spectroscopic and high energy ion beam laboratories.

References:
1. M. Prutton: "Surface physics", Clarendon Press, Oxford, 1983
2. D. Briggs, M. P. Seah: "Practical Surface Analysis" I-II, Wiley and Sons, 1992
3. Giber J. et al.: "Szilárdtestek Felületfizikája", Mûszaki Könyvkiadó, Budapest, 1987
4. O. Brümmer, J. Heydenreich, K. H. Krebs, H. G. Schneider: "Szilárd testek vizsgálata elektronokkal, ionokkal és röntgensugárzással", Mûszaki Könyvkiadó, Budapest, 1984

Name of the teacher: **Dr. Csaba Cserháti** **PF3/316-93**

Electron Microscopy

Transmission electron microscopy:
Elements of a Transmission Electron Microscope. Electromagnetic Lenses, Objective Lens, Electron Gun, Lens Aberrations. Sample Preparation. Electron Diffraction, Ewald-Theory, Orentation and Phase analysis, Textures, Kikuchi lines and Bands and their Application. Convergent-beam Diffraction. Kinematic and Dynamic Theories of Diffraction, Diffraction Contrast, Identification of Defects. High-Resolution Electron Microscopy, Resolution, Image-Interpretation, Image-simulation, Image computer processing.

Analytical Electron Microscopy, X-ray Microanalysis, Energy-loss analysis, Scanning Electron Microscopy.

References:
1. L. Reimer: Transmission Electron Microscopy, Springer, 1983
2. Gy. Radnóczi: A transzmissziós elektronmikroszkópia és az elektrondiffrakció alapjai, KLTE jegyzet, 1990

3. S. Amelinckx, R. Gevers, J. Van Landaut (eds.): Diffraction and Imaging Techniques in Material Science. North Holland 1978

Name of the teacher: **Dr. Gábor Langer** **PF3/317-93**

Thin Film Deposition Techniques

Gases. Gases in vacuum system. Measurement of pressure. Vacuum materials and components. Vacuum system. Thermal evaporation. electron-beam evaporation. Sputtering. Magnetron sources. Sputtering characteristics.

References:
1. A. Chambers, R. K. Fitch, B. S. Halliday: Basic Vacuum Technology, Adam Hilger, Bristol and New York, 1989
2. B. N. Chapman: Glow discharge processes, Wiley, New York, 1980
3. I. E. Greene, S. A. Barnett, J. E. Sundgren and Rockett: Ion beam Assisted Film Growth, Ed. by T. Itoh Elsevier, Amsterdam 1988

Name of the teacher: **Dr. Dezső Beke** **PF3/319-93**

Plastic Deformations and Fracture

Basic mechanisms of plastic deformations: dislocation glide, dislocation climb, creep and twinning. Deformation mechanism maps. Non-linear effects in plastic deformations. Hardening mechanisms. Superplasticity. Nucleation and growth of fractures. Mechanisms of fractures (brittle and ductile fracture, role of interfaces). Maps of fracture mechanisms.

References:
1. R. W. Cahn and P. Haasen: Physical Metallurgy North-Holland, 1983, Amsterdam
2. J. Giber et al.: Szilárdtestek felületfizikája Mûszaki Kiadó, Budapest, 1987
3. F. R. N. Nabarro (ed.) Dislocation in Solids, Vol. 4. North Holland, Amsterdam, 1979

Name of the teacher: **Dr. Zsolt Gulácsi** **PF3/320-93**

Theory of Magnetism

Itinerant electron ferromagnet. Itinerant-electron antiferromagnetism in one and two band systems. Excitonic systems. Magnetic impurities and the Anderson model. Nagaoka compensation and the Kondo problem, Localised systems. Exchange interaction. Weiss field. The influence of the dimensionality. Exact solutions in 1D: Ising model. The exact solution of 2D Ising model. Magnons. Applications of the Green function method for the description of magnetic properties in localised systems, Hartree-Fock and other type of solutions. correlation functions, susceptibility, critical exponents. The case of the infinite dimension.

References:
1. Elméleti fizika, L. D. Landau, E. M. Lifsic, L. P. Pitajevszkij sorozat, Nauka, 1978

2. Effectiv Field Theories of Magnetism, J.S. Smart, 1966
3. Quantum Theory of Many-Particle Systems, A. L. Fetter, J. D. Walecka, McGraw-Hill Book Company, 1971

Name of the teacher: **Dr. Dezső Beke** **PF3/322-94**

Nonequilibrium Materials

Thermodynamics of nonequilibrium metallic materials. Diffusion in nonequilibrium. Mechanical instabilities. Solid-state amorphosation in multilayers (neutron reflection studies). Solidification of metastable materials. Mechanical alloying. Transmission electron microscopic studies on nonequilibrium system. Nuclear methods (m^+, p^+, e^+). Structure and properties of grain boundaries. Nanocrystalline materials

Name of the teacher: **Dr. Zsolt Gulácsi** **PF3/323-94**

Many-Body Calculation Techniques and Applications

(Same as PF1/37-93)

Name of the teacher: **Dr. Gábor Langer** **PF3/324-94**

Thin Films

Formation of layers by molecular beam epitaxy
Multilayers
Formation of multilayers by magnetron sputtering
Structure evolution in polycrystalline films
Structure of multilayers
Amorphisation in multilayers
Investigation of multilayers by X-ray diffraction
Al-metal interaction in thin films
Investigation of thin films by Mössbauer-spectroscopy
Formation of metastable layers by ion-implantation
Structure of layers in semiconductor materials
Depth sensitive measurement by low energy positrons
Ion-mixing during the ion-sputtering
Investigation of thin films by ions
Investigation of multilayers by magnetic X-ray dichroism

Name of the teacher: **Dr. László Kövér** **PF3/326-95**

Electronic structure of surface and interface formations

Local potentials, description of inner shell binding energy shifts by the point-charge model, experimental determination by electron spectroscopic methods. Surface binding energy shifts, interpretation, experimental determination. Relaxation of core-ionized surface atoms, experimental determination of the relaxation energy by Auger parameter measurements. Atomic, molecular and collective excitation processes on surfaces and interfaces, experimental observation. Local charges, charge transfer in alloys and at semiconductor interfaces. Experimental methods for determining local work functions. Interpretation of valence band electron structures in crystals by cluster MO methods, determination of the density of electron states from valence band photoelectron spectra. Study of local density of states and electron-electron, hole-hole correlations by analyzing Auger spectra. "Engineering" of electron structures, quantum corrals.

Name of the teacher: **Dr. Ferenc Kun** **PF3/327-95**

Computer simulation

Theoretical foundations of the Monte-Carlo method and its application. Simple sampling and importance sampling. Boundary conditions. Finite-size effects. Random walks. Diffusion-limited aggregation. Percolation. Ising model. Deterministic models. Cellular automata. Molecular dynamics.

Name of the teacher: **Dr. István Szabó** **PF3/329-96**

Atomic Resolution Microscopy

Introduction: Limits of microscopy, basic techniques, basics of surface physics and UHV, image formation and processing Field Ion Microscopy: basics, atomprobe, imaging atomprobe, application examples.

Scanning Tunnelling Microscopy: The first realisation, the tunnelling process, vibration damping, piezo-electricity, control electronics, examples, image interpretation, applications.

Atomic force microscopy: The basic idea, modes of force detection, modes of operation, mechanisms of the tip sample interaction, examples.

Near-field Optical Microscopy: Overcoming the wavelength limit.

Realisation techniques, applications.

Scanning Probe Microscopy: The local probe method: main types, applications.

High resolution electron microscopy: Transmission and scanning transmission techniques, electron holography, the theory of image formation, resolution limits, HR-image simulation.

Name of the teacher: **Dr. István Szabó** **PF3/330-96**

Intermetallic compounds

Introduction: Classification, main properties, ordered crystal lattices: experimental determination, basic structures and examples.

The ground state: Ising model, energy minimisation, frustration, devil's staircase.

Order-disorder transition: Correlation function, Mean field model, cluster-variation method, phase diagram calculation.

Criticality: scaling, universality, experimental study.

Simulation methods: MC method and variations, critical slowing down. Point defects: classification, thermal equilibrium.

Diffusion: point defect motion, diffusion mechanisms, experimental techniques.

Antiphase boundaries: internal structure, domain structure, wetting transition, experimental studies.

Name of the teacher: **Dr. Dezső Beke** **PF3/331-97**

Micro- and Nanomagnetism

1. Basic knowledge on experimental ferromagnetism, including the summary of the recent theoretical results as well (Ising-model, wave-magnetism, exchange interactions, different anisotropies, domain-magnetism and structure). Magnetism of small independent particles (superparamagnetism).
2. Spin-glasses, cluster-glasses, magnetic properties of nanocrystalline materials.

Name of the teacher: **Dr. Sándor Kökényesi** **PF3/332-97**

Solid State- and Optoelectronics

Review of solid state physics and material science - based essentials in solid state- and optoelectronics on the level for PhD students, that may be useful as introduction to their research work in this field.

Material science, solid state physics and electronics as approaches to the analysis of active and passive elements and constructions of optoelectronics.

Light sources: LED, laser diodes. Photodetectors, phototransistors, photodiode. PIN, Shottky-diode. Solar cells, amorphous silicon. Optrons.

Optical waveguides. Optical fibres and cables: materials and technology. Parameters of transmission, their optimisation. Optical couplers and sensors.

Optical modulators: electro-, acusto-, magnetooptical phenomena and their applications. Non-linear optics: generation, bistability, solitons.

Optical memory, holography, data processing. Image digitalisation, displays: CCD, TV camera, panels.

Name of the teacher: **Dr. Zsolt Gulácsi** **PF3/334-97**

Quantum Phase Transitions

Short review of the theory of classical (finite temperature) phase transitions. Techniques to treat quantum fluctuations, the Trotter-Suzuki and Matsubara formalisms. Quantum phase transitions az d+1 dimensional classical problems, finite temperature as finite size in the "time" direction. Ising model in transverse field, Jordan-Wigner transformation, phase transitions from the Mott insulator. Renormalization group. The effect of disorder in quantum systems.

Name of the teacher: **Dr. Zsolt Gulácsi** **PF3/335-97**

Spin Glasses

The Sherrington-Kirkpatrick model of the spin glasses. The replica symmetric solution and the de Almeida-Thouless instability line. The Parisi Ansatz, replica symmetry breaking. Pure states and the physical meaning of the q(x) function. Ultrametric structure of the pure states. Quantum spin glasses. Ising spin glass in a transverse field.

Name of the teacher: **Dr. Zsolt Gulácsi** **PF3/336-98**

Polarization, Screening and Response Functions

Screened Coulomb potential. Dielectric function, polarization, the screening process in the Coulomb gas. Linhardt function. Instabilities, Friedel oscillations, scrrening of the magnetic moment. Ruderman-Kittel-Kasuya-Yoshida interaction. Linear response.

Name of the teacher: **Dr. Zsolt Gulácsi** **PF3/338-00**

Description of Superconductivity

Basic Phenomenology. Phenomenological descriptions, London, Ginzburg-Landau theory. Microscopical description, BCS Theory. I. and II. type superconductivity, description and characterization. Critical currents in II. type superconductors. Flux quantization. New developments, high T_c. Applications, new directions in applied research.

Name of the teacher: **Dr. Dezső Beke** **PF3/339-02**

Diffusion and segregation in nanostructures

Diffusion on nanoscale is still not well understood even if the role of structural defects (dislocations, grain boundaries) can be neglected. In this case “only” such principal difficulties arise as the problem of the transition between the continuum and discrete description, or the problem of the non-linearity (due to the strong concentration dependence of the diffusion coefficients). Furthermore the segregation kinetics are also always related two the redistribution of atoms on nanoscale and thus for the understanding of them the above questions should also be clarified. In addition, the size effects influence the equilibrium isotherms as well.

Literature:

- Bernardini, J, Beke, D.L., „Diffusion in Nanomaterials" in „Nanocrystalline materials: Properties and Applications" (Eds. Knauth, P., Schoonman, J.) Kluwer Academic Publ., Boston, 2001
- Beke, D.L. C. Cserháti, Z. Erdélyi, I.A. Szabó, "Segregation in Nanostructures" in „Advances in Nanophase materials and nanotechnology" Volume: „Nanoclusters" (ed. H.S. Nalwa) American Scientific Publ., 2002, in print

Name of the teacher: **Dr. Zsolt Gulácsi** **PF3/340-08**

Many-body systems in periodic potential

The effect of the periodic potential on the quantum mechanical behavior, fermionic quantum liquids (Fermi liquid, non-Fermi liquid, marginal Fermi liquid, Luttinger liquid), correlation effects reflected in metallic and non-metallic behavior, Mott insulators, condensates and their properties.

Bibliography: Patrik Fazekas, Lecture Notes on Electron Correlation and Magnetism, Series in Modern Condensed Matter Physics, vol. 5., World Scientific, 1999.

Name of the teacher: **Dr. Dezső Beke** **PF3/341-12**

Advanced Topics in Nanotechnology

1. Introduction to Nanoscience: Types of Nanomaterials, Nanomaterials Yesterday, Nanophenomena, Nanomaterials Today
2. Nanotechnology and Nature: Optical, Mechanical, Biomechanical and Medical Phenomena
3. The Importance of the Surface: Geometric Factors, Collective Surface Area, Surface to Volume Ratio, Spherical Cluster Approximation
4. Surface Energy I: Surface Tension of Water Droplets, Capillarity, Superhydrophobic Surfaces Revisited, Nanothermodynamics
5. Surface Energy II: Basic Crystallography, Nearest-Neighbor Model, Energy Compensation Mechanisms
6. Chemical Bonding and Synthesis: Intramolecular Forces, Strength of the C-C Bond, Intermolecular Forces, Principles of Self-Assembly, Template Synthesis
7. Topics in Solid State Physics: Band Theory for Nanoparticles, Density of States
8. Nano-Optics: Nanometals and the Surface Dipolar Plasmon Resonance, The Quasi-Static Approximation and Mie Theory, Effects of Particle Size, Shape and Orientation, Metamaterials
9. Selected Nanomaterials and Applications: Carbon Nanotubes, Quantum Dots, ZnO, Thin Films
10. Special Topics in Nano Metrology

The course is supported by the TAMOP-4.2.2/B-10/1-2010-0024 project. The project is co-financed by the European Union and the European Social Fund.

Name of the teacher: **Dr. Lajos Daróczi** **PF3/342-13**

Martensitic transformations

General description of martensitic transformations. Crystallography of martensitic transformations. Thermodynamics of martensitic transformations: the role and properties of chemical and non-chemical free energy contributions. Thermoelastic and non-thermoelastic transformations. Shape memory effect, superplasticity and superelasticity.

Martensitic transformations in different materials: Carbon steels, high alloy steels, transformation induced plasticity, copper based systems, Ti-Ni systems, other metallic and non-metallic systems. Ferromagnetic shape memory alloys. Noise phenomena in martensitic materials. Acoustic emission, Barkhausen-noise, magnetic emission, thermal emission.

Application of martensitic materials. Steels, hardening, transformation induced plasticity. Equipments based on one and two way shape memory effect. Design principles of shape memory equipments. Devices based on superelastic phenomena and high damping capacity. Magnetic shape memory devices.

Name of the teacher: **Dr. Zsolt Gulácsi** **PF3/343-14**

Theory of Strongly Correlated Systems

The course is held by Dr. Miklós Gulácsi.

Fermi and Bose liquids and their properties; The notion of Bosonization and its application technique; Luttinger liquids and their properties; Introduction to Conformal Field Theory, and applications to Condensed Matter Theory; Exactly solvable models; Bethe Anzats and its application; Heisenberg model; Hubbard model; Kondo model

Name of the teacher: **Dr. Zsolt Gulácsi** **PF3/344-14**

Quantum information and quantum computation

Numerical calculation and its characteristics, Turing machnine, Church-Turing theorem, Moore law; Quantum measurements and dynamics, information theory and thermodynamics, reversible logic; The notion of quantum bit, realization possibilities, quantum registers and their action, quantum gates, circuits, and their characteristics; Quantum algoritms, Deutsch-Jozsa, Simon, Schor, Grover; Quantum cryptography, quantum error-corrections; Cloning, entanglement, superdense coding, teleportation; Decoherence and quantum hardware.

Name of the teacher: **Dr. István Szabó** **PF3/345-14**

Introduction to spintronics

The course is held by Dr. László Szunyogh.

The coure is extending the basic knowledge of quantum mechanics and solid state physics in the new field of spintronics combining theory and applications. The main topics are as follows:

Theoretical foundations:
Electronic structure. basic calculation methods, symmetries.
Density functional theory, itinary electron magnetism,. The Stoner.model of magnetism
Description of compound with the coherent potential approximation.
Adiabatic spin-dynamics, the method of ordered local momentums
Relativistic theory. Spin-orbital coupling, magnetic anisotropy, The Rashba effect..
Spin models: Heisenberg model, Ising model.
Exchange interaction, RKKY interaction, Dzyaloshinskii-Moriya approximation.
The Landau-Lifshitz-Gilbert equation, spin-dinamics simulations.

Applications:
Magnetism at surfeces and thin films coupling oscillations, giantic magnetoresistance.
Spin based logic, magnetic domains, magnetic logic, domain wall logic.
Fundamentals of quantum computing and its possible solid state physics realisations
Medical appplications of magnetic nanoparticles, hyperthermia

References:

- Jürgen Kübler: Theory of Itinerant Electron Magnetism (Oxford University Press, Oxford, 2000)
- Peter Mohn: Magnetism in the Solid State, An Introduction. Springer Series of Solid State Physics 147. (Springer Verlag, Berlin-Heisenberg, 2003)
- Rainer Waser: Nanoelecreoncs and Information Technology (Willey-VCH 2012)

Name of the teacher: **Dr. Attila Csík** **PF3/346-14**

X-ray related technics for solid state studies

The nature and properties of X-rays, interactions with matter. The role of in-sample processes in X-ray fluorescence spectrometry (XRF). Excitation sources, optimisation of experimental parameters, measurement of fluorescence spectra. Composition analysis by X-ray fluorescence method. The quantitative evaluation of energy dispersive (ED) XRF spectra. Mathematical and experimental methods of composition analysis, the importance of specimen preparation. Comparison of ED XRF with other X-ray emission (e.g. PIXE, EPM) analytical methods.

Structural studies by X-ray diffraction (XRD) method. Fundamentals of X-ray diffraction, the effect of instrumental factors upon diffraction spectra. Structural studies of samples by X-ray diffractometer, adjustment and calibration of instrument, specimen preparation. Interpretation of diffraction measurements, determination of interplanar spacings and crystalline structures. The effect of crystal imperfections upon the line shape of Bragg-reflection, calculation of crystallite size and lattice strain from line broadening. Study of solid state materials by the applications of synchrotron radiation. Investigation of multilayer structures by small angle X-ray diffraction.

IV. Physical Methods in Interdisciplinary Researches program

Name of the teachers: **Dr. Árpád Z. Kiss et al.** (Lectures) **PF4/31a-93**
Dr. Árpád Z. Kiss et al. (Exercises) **PF4/31b-93**

Atomic and Nuclear Microanalysis

Dr. Árpád Z. Kiss: Atomic and nuclear interaction processes, characterisation of microanalytical techniques (L).
Dr. Imre Uzonyi: X-ray fluorescent analysis (XRF) (L+E).
Dr. Zsófia Kertész: Charged particle-induced X-ray emission (PIXE)(L+E).
Dr. Róbert Huszánk: Rutherford backscattering as an analytical method (RBS)(L+E).
Dr. Árpád Z. Kiss: Nuclear reaction analysis and charged particle induced gamma-ray emission (PIGE)) (L+E) (E: Dr. Zoltán Szoboszlai).
Dr. Imre Uzonyi: Ion microprobe in elemental analysis (L+E).
Dr. Kálmán Vad: Secondary Ion Mass Spectroscopy (SIMS) (L+E), (E: Dr. Attila Csik).
Dr. László Kövér: Electron spectroscopy in chemical analysis (ESCA) (L+E).
Dr. István Csige: Microradiography by solid state nuclear track detectors (SSNTD) (L+E).
Dr. László Palcsu: Application of mass spectrometry in isotope analytics (L+E).

References:

- J.R. Bird and J.S. Williams (ed.): *Ion Beams for Materials Analysis*, Academic Press Australia, 1989.
- Zeev B. Alfassi (ed.): *Non-destructive Elemental Analysis*, Blackwell Sci. Ltd. UK, 2001.
- E. Koltay, F. Pászti and Á.Z. Kiss, : *Chemical application of ion accelerators* (Handbook of Nuclear Chemistry, Eds.: A. Vértes et al.) 2011.
- M. B. H. Breese, D. N. Jamieson, P. J. C. King: *Materials Analysis using a Nuclear Microprobe*, Wiley, 1996.
- S.F. Boulyga, et al.: *Nuclear track radiography of „hot" aerosol particles*, Radiation measurements 31 (1999)131.
- Scott E. Van Bramer: *An Introduction to Mass Spectrometry*, http://science.widener.edu/svb/massspec/massspec.pdf

Name of the teacher: **Dr. Julius Csikai** **PF4/33-93**

Applications of Neutrons in Elemental Analysis

Status of nuclear methods in elemental analysis (a comparison with other instrumental analytical techniques).

Neutron sources ((a,n), (g,n) radioactive sources; ^{252}Cf(SF) sources; accelerator based sources; steady state and pulsed reactors, cold neutron sources). Activation analysis with thermal, epithermal and fast neutrons. Determination of average activating flux in complex and bulk samples. On-line and off-line methods.

Prompt gamma analysis based on accelerator and closed neutron sources. Elastic scattering analysis by backscattered fast neutrons. Utilisation of the (n, a)and (n, f) processes in the chemical analysis. Delayed neutron method. Utilisation of secondary reactions in the elemental analysis. A combination of the neutron activation analysis with radiochemical separation method.

References:

1. J. Csikai: Handbook of Fast Neutron Generators, CRC Press Inc., Florida (1987) Vol. I.
2. S. S. Nargolwalla and E. P. Przybylowicz, Activation Analysis with Neutron Generators, John Wiley & Sons, New York (1973) Calif. Press, Berkeley (1975)

Name of the teacher: **Dr. Andrea Somogyi** **PF4/35-04**

Synchrotron radiation based X-ray microprobe methods

Introduction (characteristics of X-rays, X-ray–matter interactions; traditional X-ray fluorescence methods).
Synchrotron, synchrotron radiation.
Creation of monochromatic radiation (monochromators).
Focusing of X-rays (basic focusing elements and their working principles).
X-ray monitors and detectors.
X-ray microprobe techniques: micro-XRF, micro-XANES, X-ray fluorescence tomography, micro-diffraction, absorption and phase contrast tomography.
Applications in environmental science, geology and material science.
Comparison with other accelerator-based and laboratory micro-analytical techniques.

References:

1. Koen H.A. Janssens, Freddy C.V. Adams, Anders Rindby, *Microscopic X-Ray Fluorescence Analysis,* John Wiley & Sons, LTD, Chichester, 2000.
2. Bacsó, Á. Pázsit, A. Somogyi, *Energy Dispersive X-Ray Fluorescence Analysis* in Nuclear Methods in Mineralogy and Geology Techniques and applications, A. Vértes, S. Nagy and K. Süvegh eds., New York, London, Plenum Press, 1998, pp. 165-215.
3. Koltay, F. Pászti, Á.Z. Kiss, L. Vincze, F. Adams, *Chemical Applications of Accelerations,* in Handbook of Nuclear Chemistry, A. Vértes, S. Nagy, Z. Klencsár eds., Kluwer Academic Publishers, Dordrecht, NL, 2003, vol. 3, pp. 387-441.

Name of the teacher: **Dr. György Csepura** **PF4/36-04**

Radiation Protection

Summary. Radiation protection history. Concept of radiation protection, quantities and possibilities of measurement. Provision of law. National organizations. Ionization radiate in practice. X ray machines (“closed and opened”) radioaktive matter in practice. Measure of thickness, level, thich e.g.. Diagnostic and therapy in medical.
Cosmic ray. Spaceship, in particular for astronautes. Dose rate and radiation protection. (UV and radiate region)

Names of the teachers: **Dr. László Palcsu, Dr. István Csige, Dr. Mihály Molnár**
PF4/37-09

Nuclear Environmental Protection

-Nuclear power plants, radioactive waste treatment and disposal.
-Environmental impact of different nuclear power plants (normal operation, accidents, shutdown, waste)
-Nuclear power plant of new types with reduced environmental impact and enhanced safety
-Reactor diagnostics with noble gases
-Examination of radioactive waste, hard-to-measure isotopes.
-Gas generation during radioactive waste disposal
-Monitoring of radioactive emission to the groundwater and the atmosphere.

Literature:

11. Molnár M.: Experimental investigation of gas generation in low and intermediate low level radioactive waste. PhD Theses, Debreceni Egyetem, Debrecen 2003 (in Hungarian, with English summary)
12. Charles B. Ramsey, Mohammad Modarres: Commercial Nuclear Power: Assuring Safety for the Future, BookSurge Publishing 2006

Names of the teachers: **Dr. Mihály Molnár, Dr. László Palcsu** **PF4/38-09**

Radioactive dating

The course is held partly by Prof. Thomas Rauscher in English.

Dating of cosmic ages using isotopic methods (measurement of elapsed time between a supernova explosion and the first condensation of solids, irradiation-time measurements in meteorites, date of the impact of meteorites), Methods of geochronology (U/Th/Pb-, K/Ar-, Ar/Ar-, Rb/Sr-, Sm/Nd-, Lu/Hf-, Re/Os-, U/He-, U/Th- and fission track methods). Dating of soil and carbonate deposits (thermoluminescence dating, C-14 method). Water age determination (C-14, H-3, Freon, SF6, Kr-85 and Ar-39 method). Dating for archeology using (bio) physical measurements (radiocarbon dating, dendrochronology, using elemental analyses for dating of man-made historical artifacts). Dating by global (radio) markers (C-14 and H-3 bomb-peak, Cs-137 from Chernobil).

References:

1. Aitken, M.J. 1985: *Thermoluminescence dating* (Acadmic Press, London)
2. Bowen, R. 1988: *Isotopes in the Earth Sciences* (Elsevier, London) p. 647
3. Clark. ID, Fritz, P, 1997: *Environmental isotopes in Hydrogeology* (Boca Raton, CRC Press)
4. Dalrymple, G.B. 1991: *The Age of The Earth* (Stanford Univ., Stanford) p. 474
5. Dean, J.S., Meko, D.M., Swetman, T.W. (eds.) 1994: *Tree rings, Environment and Humanity* (Radiocarbon, Tucson)
6. Matsuda, J. (ed.) 1994: *Noble Gas Geochemistry and Chosmochemistry* (Terra, Tokyo) p. 386
7. Taylor, R.E., Long, A., Kra, R.S. (eds) 1992: *Radiocarbon After Four Decades- An Interdisciplinary Perspective* (Springer-Verlag, New York)

Names of the teachers: **Dr. Zsófia Kertész, Dr. Mihály Molnár** **PF4/39-09**

Atmosphere and climate

The coarse describes the properties of the atmospheric constituents and their effects on the global climate, as well as it gets an insight view of the physics an chemistry of the atmosphere.

- Constituents influencing the climate, air pollution
- Climate models, climate theories – IPCC models
- Atmospheric aerosol: origin, transport, physical and chemical properties, its role in the radiation balance of the Earth
- Changes in the concentrations of the greenhouse gases, their measuring techniques; changing in the quantity of the atmospheric fossil CO2, its measuring techniques (^{14}C method, CO method, etc.) The sources of CH_4 in the environment (natural, antropogenic) Detection of the changes of carbon-cycle with the help of global monitoring network.
- Ozone: stratospheric ozone layer, tropospheric ozone.

References:

1. Boeker, E. and van Grondelle, R.: Environmental Physics, John Wiley & Sons, Chicester, 1995.
2. Protecting the Earth's Atmosphere, An International Challenge, Interim Report of the Study Commission of the 11th German Bundestag "Preventive Measures to Protect the Earth's Atmosphere" Publ. by the German Bundestag, Publ. Sect., 1989.
3. Reid, S.J.: Ozone and Climate Change, A beginner's Guide, *Gordon & Breach Science Publishers, Australia,* 2000.

Name of the teacher: **Dr. Ferenc Kun** **PF4/310-10**

Computer simulation

(See PF3/327-95)

Names of the teacher: **Dr. Zsófia Kertész** **PF4/311-12**

Atmospheric Aerosol Sampling Procedures and Analysis Techniques Using Ion Beam and XRF

1. Basics of ion beam analysis
2. Aerosol sampling methods
3. Basics of PIXE
4. Atmospheric aerosols
5. Aerosols and health and climate
6. Regulations and policy in the field of air pollution standards
7. General information about data evaluation
8. Analytical data treatment

The course is supported by the TAMOP-4.2.2/B-10/1-2010-0024 project. The project is co-financed by the European Union and the European Social Fund.

Name of the teacher: **Dr. Ágnes Nagy** **PF4/312-12**

Non-linear Phenomena, Chaos

(See PF1/315-93)

Name of the teacher: **Dr. Ferenc Kun** **PF4/313-12**

Physics of Complex Systems

Detailed weekly schedule of the course

Week 1: Definition of complex systems, basic notions. Examples for complex systems. Methodology of the investigation of complex systems.
Week 2: Quantitative characterization of spatial structures, introduction to fractal geometry. Definition of fractal dimension. Classification of fractals. Self similarity.
Week 3: Numerical methods for the determination of fractal dimension. Measuring fractal dimension based on two dimensional digital projections. Box-counting and Sand-box methods and their efficient computer implementation.
Week 4: Single-scale and multi-scale fractals. Analytical determination of the fractal dimension of deterministic fractals based on self similarity. Composite fractals.
Week 5: Introduction to multifractals. Completing fractal structure with probability measures. Determination of the dimension spectrum of multifractals. Analytically solvable multifractal problems. Numerical methods for the analysis of multifractals.
Week 6: Density index of multifractals, the f-alpha spectrum. Practical applications of multi-fractals.
Week 7: Characterization of temporal structures, average fluctuation function. Multi-fractal analysis of time series.
Week 8: Structured surfaces and interfaces. Self-affine and fractal surfaces. Experimental and theoretical investigation of surface structures
Week 9: Power law distributions in physics. Physical mechanisms leading to power law distributed quantities, limit theorems, algorithm of preferential attachment.
Week 10: Cellular automata models of complex systems. Lattice gas models and their computer simulation.
Week 11: Physics of complex networks. Random graphs, small world and scale free networks. The Watts-Strogatz rewiring algorithm. Characterization of network topologies: clustering coefficient, degree distribution, and average diameter of networks. Application of networks for cellular automata models.
Week 12: Dynamic instabilities in driven dissipative systems. Self-organization. Necessary conditions for the emergence of self-organized critical states in driven dissipative systems.
Work 13: Critical phenomena and complexity, a critical comparison. The role of driving, dissipation, and relaxation for the emergence of avalanches. Separation of time scales of driving and relaxation.
Week 14: Applications of the physics of complex systems. Forecasting of catastrophic events in complex systems.

Literature

1. D. L. Turcotte, Fractals and Chaos in Geology and Geophysics (Cambridge University Press, 1996).
2. 2. H. Jensen, Self-Organized Criticality (Oxford University Press, 1997).
3. A.-L. Barabasi and H. E. Stanley, Fractal Concepts in Surface Growth (Cambridge University Press, 1998).
4. K. Christensen and N. R. Moloney, Complexity And Criticality (Imperial College Press Advanced Physics Texts, 2005).
5. H. Takayasu, Factals in the Physical Sciences (Manchester University Press, 1990).

Name of the teacher: **Dr. István Csige** **PF4/315-12**

Subsurface Flow

Physics of subsurface flow. Hydrogeological and gasgeological modeling. Water flow in the saturated and in the vadose zones. Trasport of pollutants. Gas flow in the vadose zone. Trasport of radon. Numerical methods: basics of finite difference and finite element methods. Modeling: construction of conceptual, mathematical, numerical and computer models. Building models with Visual Modflow and COMSOL Multyphysics programs.

The course is supported by the TAMOP-4.2.2/B-10/1-2010-0024 project. The project is co-financed by the European Union and the European Social Fund.

Name of the teacher: **Dr. Mihály Molnár** **PF4/316-13**

Geochronology and Paleoclimate

The course is held by Prof. A. J. Timothy Jull in English.

We will discuss some methods of determining the age of events in the Quaternary and the significance of paleoclimate changes in the last Glacial/Interglacial transitions.

We will highlight the following, with examples of applications:
1. Radiocarbon dating
2. Uranium-Thorium dating
3. K-Ar dating
4. Cosmogenic nuclide dating: including studies of exposure age, erosion rates and depth profiles
5. Luminescence method (TL and OSL)
6. Applications of these methods to climatic change during the last glacial and glacial-interglacial transition: what do we learn from these studies, problems and controversies.

Students will be expected to discuss these and write a short report on a specific subject.

References:

1. Dunai T. 2010. COSMOGENIC NUCLIDES: Principles, Concepts and Applications in the Earth Surface Sciences. Cambridge: Cambridge University Press.
2. Berger, A. and Loutre, M.F. 2007. Milankovitch theory and paleoclimate. In (Elias, S. ed) Encyclopedia of Quaternary Science. Amsterdam: Elsevier. Pp. 1017-1022.
3. Jull, A. J. T. 2006. Radiocarbon Dating: AMS Method. In Encyclopedia of Quaternary Science (ed. S. Elias), Elsevier: Amsterdam. pp. 2911-2918

Name of the teacher: **Dr. Ferenc Kun** **PF4/317-14**

Perl Programming and Networks in Computational Biology

The course is held by Dr. Illés Farkas (ELTE).

1. Fields of Bioinformatics, Results and goals.
2. Data collection.Sequencing, microarray, 3d structure, non+coding RNA, interactions.
3. Data handling. Manual curation. Types of databases.
4. Programming. Introduction to Perl. Scalar variables.
5. Perl list and hash variables.
6. Context dependence in Perl. Default variables. File I/O.
7. Perl regular expressions. Pattern matching.
8. Perl built+in functions. References.
9. Writing functions. Perl one+liners.
10. Clustering molecular biological data and building graphs.
11. Protein+protein interactions. Gene ontology. Transcription regulatory networks.
12. Data analysis with networks. Erdős+Rényi model,small+world and scale+free models.
13. Biological network models. Centrality and lethality. Structural interaction network.

Name of the teacher: **Dr. Ferenc Kun** **PF4/318-14**

Criticality and Complex Systems

The course is held by Dr. Frank Raichel in English.

- Introduction: Complex Systems
- Random Variables, Stochastic Processes, and Markov Processes
- The Langevin Equation
- Brownian Motion
- The Fokker-Planck Equation
- Non-Gaussian and non-Markovian processes
- Evaluation of Random Series in time and in scale
- Criticality and percolation
- self-organized criticality
- The Oslo model, fracture and earthquakes
- Complex networks
- Econophysics

Name of the teacher: **Dr. Mihály Molnár** **PF4/319-14**

Meteorites, the Early Solar System and Nuclear Astrophysics

The course is held by Prof. Ulrich Ott in English.

- Meteorites: their classification and chemical composition
- Meteorites and Solar System abundances: elements and isotopes
- Methods for isotopic analyses and sources of isotopic variations
- Ages of meteorites (formation, metamorphism, cosmic ray exposure)
- Meteorites and the Early Solar System: Extinct radioactivities
- Non-radiogenic isotope anomalies – bulk meteorites
- Stardust grains: isotopic compositions, stellar sources and nucleosynthesis in stars

Name of the teacher: **Dr. Róbert Erdélyi** **PF4/320-15**

Waves

Studying hyperbolic differential equations with applications to wave phenomena in key topic for modern physics. This module looks at some important wave motions with a view to understanding them and to developing from first principles the key mathematical tools. We begin with waves on strings (e.g. a piano or violin), developing the concept of standing and propagating waves, and normal modes in uniform and non-uniform waveguides. We use Fourier and Laplace methods to solve some problems and indicate developments to waves on membranes (2D) and the use of Fourier integrals. Next we consider acoustic (3D) waves in the atmosphere (e.g. organ, clarinet) and stress the mathematical similarities with waves on strings (1D) and membranes (2D). Water waves are interesting in that they are not governed by a wave equation yet can be described by similar mathematics to waves on strings. In this context, the concepts of dispersion and group velocity are introduced. The course concludes with consideration of “traffic waves” as the simplest example of nonlinear waves, introduced the very powerful method of characteristic.

Name of the teacher: **Dr. Róbert Erdélyi** **PF4/321-15**

Solar Magnetohydrodynamics

Solar Magnetohydrodynamics has been successfully applied to a number of astrophysical problems (e.g. to problems in Solar and Magnetospheric Physics), as well as to problems related to laboratory physics, especially to fusion devices. This module gives an introduction to classical magnetohydrodynamics with focus on solar applications. Students will become familiar with the system of magnetohydrodynamic equations in ideal and dissipative forms, with main theorems that follow from this system (e.g. conservation laws, anti-dynamo theorem, MHD spectrum). They will study the simplest magnetic equilibrium configurations (contact discontinuity, slab geometry, cylindrical and spherical geometry, elliptical waveguides), propagation of linear and weakly nonlinear (e.g. solitary) waves, MHD shocks in uniform, non-uniform, stratified, structured (slab and cylindrical geometries), time-dependent waveguides and magnetohydrodynamic stability. Application to solar/space observations will be made (e.g. introducing the concept of solar magneto-seismology).

Name of the teacher: **Dr. Róbert Erdélyi** **PF4/322-16**

Advanced Solar Magnetohydrodynamics

Solar Magnetohydrodynamics is widely applied to a number of space and heliophysical plasma problems (e.g. to problems in solar, magnetosphere and Space Weather physics). This course, building on the pre-requisite course of Solar Magnetohydrodynamics, embarks on classical magnetohydrodynamics with focus on specific and advanced solar MHD applications. Students will become familiar with the method of MHD characteristics, system of MHD eigenvalue problems, MHD spectral theory in ideal and dissipative magnetised plasmas, stability theorems, absolute and convective instabilities, resonant absorption, phase mixing in inhomogeneous MHD plasmas, and magnetic reconnection. The course will address advanced magnetic equilibrium configurations (including steady state contact discontinuity, multiple slab and cylindrical geometry) and propagation of linear MHD waves in such systems. Application to dynamic solar and space observations will be made (e.g. for waveguide models of advanced solar magneto-seismology).

Name of the teacher: **Dr. Róbert Erdélyi** **PF4/323-16**

Sunpy

Sunpy (www.sunpy.org) is a modern, open-source software package written in Python. It is a high-level computing language and software tool, indispensible to analyse solar ground- and space-based data efficiently. SunPy was specifically geared towards allowing the solar physics community to benefit from Python's extensive scientific environment and powerful visualisation capabilities. Students will gain a working knowledge of Python, particularly for the purposes of solar and astronomical data handling and visualisation. Introduction to the Unix operating system and version control software will be taught in relation to Sunpy to familiarise themselves for collaborative code development. Throughout the lecture series and the associated exercises best practices in programming with the aim of creating the best scientific software for efficiency and reproducibility will be aimed at. The course is delivered in two types of format: lectures and practicals. There is some flexibility with the balance of these two approaches, helping to achieve the most effective retainment of knowledge. Lectures themselves are presented using the IPython Notebook, an interactive Python environment, which allows us to utilise a "live-coding" approach, a distinctly more effective technique compared to traditional lecturing styles. In addition to the main lectures, the practical exercises function best with one or two helpers to explain concepts and help debug as the lesson progresses.

Syllabus: Bash, command line programming; Git, version control; Basic Python; Advanced Python; Using Units and Quantities in programming; Images and Plotting Images; Images in Astronomy/Solar Physics; Reading Data into Astropy Tables; Obtaining Solar and Astro Data; Time Series Data

Name of the teacher: **Dr. Róbert Erdélyi** **PF4/324-18**

Introduction to Plasmaphysics

Did you know that more than 98 per cent of material in the Universe is in plasma state? Did you know the atmosphere of stars like the Sun is also in plasma states with temperatures of a few millions of degree K? And finally, did you also know that the atmosphere of the planets in the Solar System strongly interact with plasma flows originating from the Sun causing phenomena like the Aurora? With the current increase in interest in controlled fusion and the widespread use of plasma physics in space research and relativistic astrophysics, it makes sense for the study of plasmas to become a part of a postgraduate student's basic experience, along with subjects like thermodynamics, nuclear physics or quantum mechanics.

This postgraduate course, having a pre-requisite of a good working knowledge of BSc theoretical physics, will introduce you in a unique way to modern plasma state physics. There is a guiding principle that the algebraic steps as an exercise for the student do not let obscure the physics. Therefore, by large, the treatment of plasmas will be as two interpenetrating fluids. The two-fluid picture is both easier to understand and more accurate than the single-fluid approach, at least for low-density plasma phenomena. In this module, you will gain knowledge on neutral fluids and plasmas in a unified scheme, clearly indicating similarities and their differences. Also, both the macroscopic (continuum) and microscopic (particles) theories will be covered, establishing a connection between them.

Throughout, key samples from astrophysics (with special attention to solar and astrophysics as the Sun being the most proxy space plasma laboratory) will be addressed, though no previous knowledge of astronomy and astrophysics is assumed. Finally an introduction to laser-produced and industrial plasmas with conceptual development of fusion plasmas physics is placed in its historical context at the end of the course.

Suggested literature:
AR Choudhuri: The Physics of Fluids and Plasmas;
R Dendy: Plasma Physics: An Introductory Course;
FF Chen: Introduction to Plasma Physics

Name of the teacher: **Dr. Ferenc Kun** **PF4/325-18**

Complex networks

The course covers the following topics:

- Relation of networks to complex systems. Network as a graph, the basics of graph theory. Directed and undirected graphs. Node degree, average degree, degree distribution. Adjacency matrix. Weighted networks. The Metcalfe-law. Path and distance, shortest path, diameter, average path. Connectivity. Clustering coefficient.
- Random networks. The Erdős-Rényi model. Small world networks, six-step theory. WattsStrogatz rewiring algorithm. Scale free networks. The Barabási-Albert model.

Growth and preferential attachment. Extensions of the Barabási-Albert model. Universality.

- Ultra-small world features. The degree distribution exponent. Generating networks with arbitrary degree distribution. The configuration model. The hidden parameter model. Measuring preferential attachment. Non-linear preferential attachment. Origin of preferential attachment.
- Correlated networks. Analysis of correlated networks. Generating correlated networks. Robustness of networks. Percolation of networks. Average cluster size, order parameter, correlation length. Inverse percolation transition. The Molloy-Reed criterion. Robustness against attack. Failure avalanches and their modelling. Model of failure spreading. Branching model, avalanche exponent. Designing robust networks.
- Communities on networks. Social and biological networks. Characterization of communities on networks. Identification of communities on networks. Spreading phenomena. Modelling epidemic spreading. Network epidemics. Networks of social contacts. Immunization. Forecasting of epidemic outbreaks.

Recommended Literature Barabási Albert László, Network Science (Cambridge University Press, 2016). Mark J. Newmann, Networks (Cambridge University Press, 2013).

Name of the teacher: **Dr. Ferenc Kun** **PF4/326-18**

Universality classes in non-equilibrium systems

The course is held by Dr. Géza Ódor Géza.

The course covers the following main topics of the statistical physics of non-equilibrium systems:

- Emergence of non-equilibrium universal phenomena. Characteristic quantities and critical exponents of non-equilibrium universality classes. Field theoretical description and the renormalization group method. The Keldysh formalism, local scale invariance.
- Effect of disorder on non-equilibrium systems. Rare regions theory. The Harris criterion. Basic dynamics of non-equilibrium systems. Cluster definitions, relation of the critical point and geometrical percolation.
- Universality of Z_2 symmetry non-equilibrium systems. Classes and mappings of the Potts model. The q-d phase diagram. The weak universality hypothesis. The effect of long range interactions and diffusion on the critical behavior of phase transitions. Phase transitions of two-dimensional, non-equilibrium XY models. Driven lattice gas universality classes in two dimensions.
- Mean field universality classes of one-component generalized reaction-diffusion models. Directed percolation (DP) hypothesis and its applications. Hyper-scaling relations of absorbing state phase transitions. Non-equilibrium boundary conditions. Effect of disorder on the DP universality class.
- Critical behavior of n-CP (binary, trimer ...(n>1)) universality classes. The generalized disease spreading process, its phase diagram and relation to isotropic percolation. Voter model classes in one and two dimensions.

- Asymptotic dynamics of annihilating random walks in different dimensions. The parity conserving universality class, its representations and upper critical dimensions. Persistence and its scaling relations.
- The phase diagram of BARWe and Lévy flights. The effect of competing reaction/diffusion in reaction-diffusion systems. Scaling behavior of systems with first order transitions. Scaling behavior of multi-component AB->0 and BARW models. The Edwards-Wilkinson scaling exponents.

Recommended literature Géza Ódor, Universality In Nonequilibrium Lattice Systems: Theoretical Foundations (World Scientific Publishing, Singapore, 2008).

Name of the teacher: **Dr. István Szabó** **PF4/327-18**

Atomic Resolution Microscopy

(*See:* **PF3/329-96**)

Name of the teacher: **Dr. Sándor Mészáros** **PF4/328-19**

Superconductivity

(*See:* **PF3/36-93**)

V. Particle Physics program

Name of the teacher: **Dr. István Angeli** **PF5/31-95**

High Energy Accelerators I.-II.

Introduction. Ion sources. An overview of "traditional" accelerator types. Principles and conditions of operation. Direct-voltage and resonance accelerators. Phase stability. Betatron oscillations. Criteria of weak and strong focusing. Bases and operation criteria for alternating-gradient accelerators. Heavy-ion accelerators for medium and high energies. Transfer of the accelerated beam, focusing and directing to the target. Electrostatic and electromagnetic quadrupole lenses.

The physics of charged particle beams. Characteristics of beams. Laminar beams without self-fields. Systems with axial symmetry. Two-dimensional systems. Laminar beams with self-fields. Non-laminar beams without collisions. Beams with scattering and dissipation. Radiation losses. Longitudinal and transversal waves and instabilities in beams. Dynamic phenomena in bunched beams.

Circular accelerators and storage rings. Edge focusing. Parametrisation of the transverse motion. Imperfections and resonances of orbits. Chromatic effects. Longitudinal beam dynamics. Coherent instabilities. Damping of oscillations, quantum excitations. The importance of colliders, special aspects of operation. Storage rings. Production and application of secondary particle beams (antiproton, positron, neutrino). "Cooling" of diverging antiproton beams. Linear accelerators for heavy particles. Linear electron accelerators with pulsed and continuous beams.

Name of the teachers: **Dr. Gábor Dávid, Dr. Sándor Nagy** **PF5/33-95**

Modeling, Simulation, Analysis in Experimental Particle Physics

The course is an introduction to the use of simulation and statistical analysis in the design of experiments and analysis of data in elementary particle physics.

The topics to be covered include general considerations in experiment design; nature of data recorded by elementary particle physics experiments; practical approaches to simulation of statistical processes; physics event generators; simulation of the response of different types of detectors to neutrinos, photons, electrons, muons, and long-lived hadrons; measurements of acceptance, efficiency, and resolution; kinematical fitting; estimation of parameters and their systematic and statistical uncertainties from measurements; and hypothesis testing.

The lectures will rely on examples from past and current particle physics experiments to illustrate the main points of the course, and the laboratory projects will allow the students to gain experience in the application of simulation and statistical analysis to typical experimental particle physics problems and to also become acquainted with computer software widely used in the field for this purpose.

Name of the teacher: **Dr. Péter Raics** **PF5/311-95**

Particle Detectors

Physical problems and requirements in high energy physics. Data to be measured, precision. Signal to noise ratio in particle physics experiments.

Interactions of gamma-radiation with matter. Slowing-down processes of charged particles. Gas-filled detectors: proportional, streamer, drift chambers. Utilization of scintillators. Semiconductor spectrometers. Position-sensitive detectors: visual and electronic tracking. Magnetic fields. Particle identification, determination of energy and momentum. Correlation measurements.

Electromagnetic, muon and hadron calorimeters. Triggering complex systems. Local event selection. Acquisition, transfer, evaluation and analysis of data for high number of detector channels. On-line and off-line analysis. Data formats. Simulated data in the analysis. comparison to models.

Name of the teacher: **Dr. Kornél Sailer** **PF5/312-95**

Introduction to Quantum Field Theory

(Same as PF2/315-93)

Name of the teacher: **Dr. Kornél Sailer** **PF5/314-95**

Symmetries and Symmetry Breaking in Quantum Field Theory

(Same as PF2/317-93)

Name of the teacher: **Dr. Gyula Zilizi** **PF5/316-95**

Electronics in the Experimental Particle Physics

Accelerators and their control in the particle physics. Measurements, control and data acquisition of physical environment at the high energy accelerators. Basis of electronic event detection: electronic equipment of detector readout, calibration and control. Data transmission methods of large amount of data in particle physics experiments. Hardware problems of long distance data transmission and data evaluation in the experiments. Radiation damage of electronic devices, the influence of the radiation on the operation of equipment utilized in the experiments.

Name of the teacher: **Dr. Zoltán Trócsányi** **PF5/317-95**

Standard Model

(Same as PF2/321-94)

Name of the teacher: **Dr. Zoltán Trócsányi** **PF5/318-95**

Grand Unified Theories

A short review of the standard model; successes and problems. The SU(5) grand unification model. The group structure. Spontaneous symmetry breaking. Energy-dependent coupling constants. Proton decay. The problems of the minimal SU(5) model. The SO(10) GUT model. Supersymmetric models. The concept of supersymmetry, supersymmetrical particles.

Name of the teacher: **Dr. Zoltán Trócsányi** **PF5/320-97**

Perturbative Quantum Chromodinamics I.-II.

Part I.

We discuss the perturbative description of QCD - the theory of the strong interactions. The main chapters are:

- The QCD Langrangian
- UV renormalization of QCD
- Renormalization group
- Physical examples:
  - electron-positron annihilation into jets (leading order, next-to-leading order and the dipole method, cut diagrams, helicity formalism)
  - deep inelastic scattering (factorization theorem)
  - hadron-hadron scattering

Part II.

We discuss the extension of the applicability of the fixed order perturbation theory.

1. Treatment of soft-gluon divergence's:
   - resummation at the edge of the physical region, and inside of the physical region (examples: thrust, C parameter, production of large transverse momentum jet pairs in hadron collisions)
2. Estimation of power corrections using resummation of renormalon chains (Drell-Yan process, hadronic shape variables)

Name of the teacher: **Dr. József Cseh** **PF5/321-97**

Symmetries in Two-Body and Many-Body Systems

(Same as PF2/32-93)

Name of the teacher: **Dr. Zsolt Schram** **PF5/322-97**

Lattice Field Theory

Path integral quantization. Scalar field on the lattice. Fermions. Abelian and non-Abelian gauge fields on the lattice. Analytical methods. Monte Carlo simulations. Finite temperature field theory on the lattice. Quark confinement.

Name of the teachers: **Dr. Kornél Sailer** **PF5/323-98**

General Relativity

Principles of special and general relativity. Manifolds, tensors. Curvature. Einstein's equation. Homogenous isotropic cosmology. The Schwarzschild solution. Special topicsÉ casual structure, singularities, black holes. Quantum effects.

Name of the teacher: **Dr. Dezső Horváth** **PF5/326-00**

The Standard Model and its experimental tests

Topics, Term 1:

Symmetries and conserved quantities
- Global gauge symmetries: U(1), SU(2), SU(3)

The static quark model
- Flavour SU(3): the first three quarks
- Fundamental quantum numbers: isospin, strangeness, flavour, colour
- Experimental evidence

Experimental techniques of particle physics
- Particle detection and identification, calorimeters
- Event registration, data acquisition
- Monte Carlo method, simulation,
- Statistical evaluation of data

Basic experiments: parity violation, kaon regeneration, CP violation

Local gauge symmetries and interactions
- Local U(1) = elektromagnetic interaction
- Local SU(3) = strong interaction
- Local SU(2) 🕒 weak interaction
- Strong interaction and QCD, gluons

Term 2:

Overview:
- Static quark model
- Symmetries and interactions

Weak interaction
- Parity violation
- Spontaneous symmetry breaking
- Higgs mechanism
- Mass creation
- Flavour mixing

The Standard Model

The structure of the SM

Menagerie: leptons, quarks, gauge bosons

High energy experiments: LEP and LHC

Experimental test of the SM

Z-width, mass of the weak bosons

Lepton universality

The CKM matrix

Handicaps of the SM

Extensions of the SM: GUT, SUSY, SUGRA, ...

Search for Higgs bosons

Name of the teacher: **Dr. Dezső Horváth** **PF5/327-01**

Experimental techniques of particle physics

This series is to complement the Lecturer's *Structure and Experimental Test of the Standard Model* by introducing the experimental techniques of high energy physics but they are independent, one can be taken without the other. After outlining the Standard Model the methods are demonstrated by describing concrete experiments from the early measurements of particle masses using exotic atoms and resonances up to the calorimeters of modern accelerators and to the neutrino detektors. The main topics are the following:

- Introduction: the Standard Model.
- Cross section, measuring energy and time, resonances. Particle masses.
- Detecting charged particles.
- Slowing down of charged particles. in matter, the Bethe-Bloch equation.
- Exotic atoms and their applications, muon spin resonance.
- Parity conservation and violation; CP-violation, neutral kaons. CPT-tests.
- High energy photon spectroscopy.
- Z and W physics: LEP experiments.
- Neutrino detecetors, neutrino masses.
- Hadron colliders; LHC, CMS experiment.
- e-p collider: HERA and its experiments.
- Future colliders.

Name of the teacher: **Dr. Gábor Dávid** **PF5/331-10**

Data Acquisition, Triggering and Online Monitoring

Storage ring particle accelerators, multilayer detectors; RHIC PHENIX, subdetectors of PHENIX. Clock distribution. Front End Modules (FEM), Data Collection Modules (DCM) and Event Builders (EvB) of PHENIX. Multilevel trigger systems in high energy physics experiments; implementation in PHENIX: hardware level-1 trigger and software level-2 trigger. Partitions. Data organization: events, segments, runs. Online monitoring. Online and offline calibration, afterburners.

Name of the teacher: **Dr. Zsolt Schram** **PF5/332-11**

Variational principles of theoretical physics

History of the variational principle. Mechanics: principle of virtual work. D'Alembert's principle. Action principle. Poisson algebra. Gauss principle. Lagrange method. Maupertuis principle. Optic and electrodynamics: Fermat's principle. Coulomb and Gauss laws. Ampére's law. Electrodynamics, Faraday and Maxwell. Gauge fixing and electromagnetic waves. Electrodynamics in quaternion formalism. Gravity: Spacetime metrics.Relativistic motion of point particle. Geometry of the Maupertuis principle, geodesics. Relativistic motion of a point charge, string action. Einsten-Hilbert action and Einstein equations. Thermodynamics: Entropy principle and temperature. Free energy, thermodynamic potentials. Gibbs distribution, micro- and macro-probabilities. The H theorem of Boltzmann.

Quantum mechanics: Schrödinger equation from variational principle. The Ritz principle. The Hartree-Fock method. Time dependent variational problems. Hilbert space over coherent states. The Feynman Path Integral.

The course is supported by the TAMOP-4.2.2/B-10/1-2010-0024 project. The project is co-financed by the European Union and the European Social Fund.

Name of the teacher: **Dr. Kornél Sailer and Dr. Sándor Nagy** **PF5/333-13**

Functional renormalization group method

The effective action in quantum field theory, scale dependence, the Wetterich equation. Evolution equations of simple scalar models, and the comparison of the solutions with the perturbative results. The gaussian, the ultraviolet and the infrared fixed point. Asymptotic freedom in the scalar O(N) model. Asymptotic safety, examples: Gross-Neveu model, nonlinear sigma model, sine-Gordon model. The renormalization of quantum gravity.

Name of the teacher: **Dr. Tamás György Kovács** **PF5/334-14**

Statistical field theory

- A brief recap of statistical phsyics
- The Ising model
- Monte Carlo simulation of statistical systems
- Critical phenomena, the critical point of the Ising model
- Introduction to the renormalization group
- Numerical study of the critical point of the Ising model
- Outlook: quantum field theory in particle physics

Name of the teacher: **Dr. Kornél Sailer** **PF5/335-14**

Cosmology

Facts from astronomic observations (Hubble-law, Cosmic Microwave Background Radiation). Homegeneous and isotropic Universe (Robertson-Walker-metric, Friedmann-equations and their solutions, horizonts, conform diagrams, redshift, cosmologic parameter, decelaration parameter). The matter content of the Universe and its brief history. Problems in the Big-Bang model, the inflationary Universe (inflatonfield, pre- and reheating). Gravitational instabilities (in the Newtonian physics, in the General Relativity). Primordial inhomogeneities and their characterization.

Name of the teacher: **Dr. Gábor Somogyi** **PF5/336-15**

Methods of computing Feynman integrals

High energy particle collisions allow us to study the structure and behaviour of matter on the shortest length scales. The mathematical structure underpinning the theoretical description of such collisions is perturbative quantum field theory. Feynman integrals are the basic building blocks of explicit perturbative computations in quantum field theory. The course is an introduction to the modern methods of computing Feynman integrals. Main topics covered are:

- Definition of Feynman integrals
- Basis tools: alpha- and Feynman-parameters
- Computing Feynman integrals through Mellin-Barens representations
- Integration by parts identities, reduction to master integrals
- Computation of Feynman integrals through differential equations
- Modern methods of symbolic integration
- Numerical methods of computing Feynman integrals

Name of the teacher: **Dr. István Nándori** **PF5/337-16**

Basics of functional renormalization group method

Quantum Field Theory is a natural choice to describe the physics of elementary particles. In particle physics, theories and models are defined by symmetry considerations. However, the relativistic description and quantisation leads to scale-dependent parameters which requires the so called renormalization procedure. The purpose of the present course is to give an introduction to the method of functional renormalization group which is used to perform renormalization non-pertirbatively.

Name of the teacher: **Dr. Sándor Nagy** **PF5/338-17**

Quantum renormalization group

The limitations of the traditional, single time path renormalization group (RG) method. Renormalization in Minkowski spacetime. The comparison of the Euclidean and the Minkowski RG equations in the O(N) model, phase structure, fixed points. The closed time path (CTP) formalism and its applications. The calculation of the CTP propagator and its inverse. Open and closed systems. The open and the closed time path formalism, reduced density matrix. The renormalization of the bilocal potential. The tree level renormalization and the loop contributions. The CTP RG equations. The entanglement of the system and the environment.

Name of the teacher: **Dr. Ádám Kardos** **PF5/339-18**

Introduction to Effective Field Theories

The purpose of the course is to introduce the students to the notion and techniques used in effective field theoretical calculations, in particular in Soft-Collinear Effective Theory (SCET) of Quantum Chromodynamics. We calculate the first radiative correction to the thrust distribution in e+-e- collisions and point out the importance of higher order effects by comparison to measurements. We discuss the dynamics of soft and collinear interactions and also how to incorporate multiple interactions in forms of Wilson lines, first in QED, then to the case of QCD by introducing the color charge. SCET is introduced as a universal soft and collinear factorization which decouples different collinear sectors from each other and from the soft sector encompassing all soft emissions. The explicit factorization is shown in case of the Drell-Yan process (lepton-pair production in hadron-hadron collisions) and for two-jet production in electron-positron annihilation. The full SCET analysis is carried out for the thrust distribution in order to enhance the precision of the fixed-order prediction by taking into account terms at all orders in perturbation theory.

Name of the teacher: **Dr. Zsolt Fülöp** **PF5/340-18**

Neutrino Physics

The course is held by Dr. Kai Zuber in English.

(*See :* **PF2/345-18**)