

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

## **2025.**

---

Director: Prof. Dr. Ferenc Kun

---

University of Debrecen, Faculty of Science and Technology,  
Department of Theoretical Physics  
Address: H-4026 Debrecen, Bem tér 18/b, Hungary  
Postal address: H-4002 Debrecen, POBox 400, Hungary  
Phone: +36-52-509-201, Fax: +36-52-509-258  
E-mail: [ferenc.kun@science.unideb.hu](mailto:ferenc.kun@science.unideb.hu)  
URL: <http://physphd.unideb.hu>

---

Edited by:  
Dr. László Oláh , Dr. Dóra Sohler

### Table of Contents

Atom- and Molecular physics program	3
Nuclear Physics program	5
Solid State Physics and Material Science program	7
Physical Methods in Interdisciplinary Researches program	8
Particle Physics program	10
Description of the Subjects	12

Debrecen, September 2025.

### Registered courses 2025

(A tantárgyak alábbi listája és részletes leírása megtalálható a doktori iskola honlapján is: <http://physphd.unideb.hu> )

#### I. Atom- and Molecular physics program

<i>Teacher/tutor</i>	<i>Course</i>	<i>Code</i>	<i>Type</i> <i>L,D,S,Lab</i>	<i>Hours/ Credits</i> <i>week</i>		<i>Remarks</i>
Dr. Cseh József	Symmetries in Two-Body and Many-Body Systems	PF1/319-97	L	2	2	
Dr. Csehi András	Atoms and molecules in electromagnetic fields	PF1/328-20	L	2	2	
Dr. Csehi András	Introduction to molecular quantum dynamics	PF1/329-20	L	2	2	
Dr. Erdélyi Róbert	Introduction to Plasmaphysics	PF1/326-18	L	2	2	
Dr. Gulácsi Zsolt	Many-Body Calculation Techniques and Applications I.-II.	PF1/37-93	L	2	2x2	2 semesters
Dr. Mezei János Zsolt	Low energy collisions in molecular astrophysics	PF1/330-20	L	2	2	
Dr. Nagy Ágnes	Quantum Mechanics of Classical Chaotic Systems (Quantum Chaos)	PF1/321-00	L	2	2	
Dr. Nagy Ágnes	Non-linear Phenomena, Chaos	PF1/315-93	L	2	2	
Dr. Nagy Ágnes	Density Functional Theory I.-II.	PF1/39-93	L	2	2x2	2 semesters
Dr. Pálincás József, Dr. Sarkadi László	Experimental Atomic Collision Physics	PF1/35-93	L	2	2	
Dr. Sarkadi László	Theory of Atomic Collisions	PF1/34-93	L	2	2	

Dr. Tőkési Károly	Computational Simulation of Phenomena in Physics	PF1/322-08	L	2	2	
Dr. Tőkési Károly	Basic examples in Programming	PF1/323-08	L	2	2	
Dr. Tőkési Károly (Dr. Joachim Burgdörfer)	Introduction to the theory of attophysics	PF1/325-14	L	2	2	
Dr. Tőkési Károly	Modelling of collision processes by Monte Carlo technique	PF1/327-20	L	2	2	
Dr. Vibók Ágnes	Atomic and Molecular Physics	PF1/32-93	L	2	2	
Dr. Vibók Ágnes	Atomic Physics I.-II.	PF1/31-93	L	2	2x2	2 semesters

## II. Nuclear Physics program

<i>Teacher/tutor</i>	<i>Course</i>	<i>Code</i>	<i>Type L,D,S,Lab</i>	<i>Hours/ Credits week</i>		<i>Remarks</i>
Dr. Angeli István, Dr. Nyakó Barna	Charge and Mass Distributions of Atomic Nuclei I.-II.	PF2/31-93	L	2	2x2	2 semesters
Dr. Angeli István, Dr. Rajta István	High Energy Accelerators I.-II.	PF2/340-13	L	2	2x2	2 semesters
Dr. Cseh József	Symmetries in Two-Body and Many-Body Systems	PF2/32-93	L	2	2	
Dr. Cseh József	Seminars on Nuclear Physics	PF2/330-97	L	2	2	
Dr. Elekes Zoltán	Exotic nuclear physics	PF2/342-14	L	2	2	
Dr. Erdélyi Róbert	Introduction to Plasmaphysics	PF2/344-18	L	2	2	
Dr. Furka Andrea Ilona	Evaulation of novel techniques in radiotherapy	PF2/348-22	L	2	2	
Dr. Fülöp Zsolt, (Dr. Thomas Rauscher)	Introduction to Nuclear Astrophysics	PF2/338-12	L	2	2	
Dr. Fülöp Zsolt, ( Dr. Kai Zuber)	Neutrino Physics	PF2/345-18	L	2	2	
Dr. Fülöp Zsolt, ( Dr. Jordi Jose)	Nucleosynthesis in Stellar Explosions	PF2/346-20	L	2	2	
Dr. Fülöp Zsolt (Dr. Nigel J. Mason)	Astrophysics, Astrochemistry and the Origins of Life	PF2/347-21	L	2	2	
Dr. Fülöp Zsolt,	Laboratory Astrophysics: Taking Laboratory to Space	PF2/351-24	L	2	2	
Dr. Horváth Dezső	The Standard Model and its experimental tests I-II.	PF2/339-12	L	2	2x2	2 semesters
Dr. Kiss Gábor Gyula	The origin of the chemical elements	PF2/350-23	L	2	2	
Dr. Krasznahorkay Attila	Measurements with Magnetic Spectrograph	PF2/323-94	Lab	2	2	
Dr. Krasznahorkay Attila	Experiments with magnetic mass separator	PF2/335-06	Lab	2	2	
Dr. Krasznahorkay Attila	Collective excitations in atomic nuclei	PF2/336-10	L	2	2	
Dr. Krasznahorkay Attila,	Modern nuclear instruments and methods	PF2/341-14	L	2	2	

Dr. Csige Lóránt						
Dr. Mezei János Zsolt	Calculations of molecular photoabsorption and electron collisions cross sections for astrophysics and other purposes	PF2/349-22	L	2	2	
Dr. Molnár Mihály (Dr. Ulrich Ott)	Meteorites, the Early Solar System and Nuclear Astrophysics	PF2/343-14	L	2	2	
Dr. Raics Péter	Methods for the Analysis of Nuclear Reactions	PF2/312-93	L	2	2	
Dr. Sailer Kornél	Introduction to Quantum Field Theory	PF2/315-93	L	2	2	
Dr. Sailer Kornél	String Theory I.-II.	PF2/322-94	L	2	2	2 semesters
Dr. Sailer Kornél	Symmetries and Symmetry Breaking in Quantum Field Theory I.-II.	PF2/317-93	L	2	2x2	2 semesters
Dr. Sailer Kornél	Renormalization Group Methods in Physics	PF2/328-96	L	2	2	
Dr. Sailer Kornél	TRIANGLE-Course	PF2/314-93	L	2	2	
Dr. Sailer Kornél	Finite Temperature Quantum Field Theory	PF2/327-95	L	2	2	
Dr. Sailer Kornél	Non-Equilibrium Statistical Physics	PF2/313-93	L	2	2	
Dr. Sailer Kornél, Dr. Schram Zsolt	Models and Methods in Theoretical Physics	PF2/334-02	L	2	2	
Dr. Somorjai Endre Dr. Kiss Gábor	Nuclear Astrophysics	PF2/36-93	L	2	2	
Dr. Timár János	The rotating nucleus: an experimental view	PF2/337-11	L	2	2	
Dr. Trócsányi Zoltán	Standard model	PF2/321-94	L	2	2	
Dr. Vertse Tamás	Numerical Methods in Practice	PF2/329-97	Lab	2	2	
Dr. Vertse Tamás	Nuclear Models I.-II.	PF2/35-93	L	2	2x2	2 semesters

### III. Solid State Physics and Material Science program

<i>Teacher/tutor</i>	<i>Course</i>	<i>Code</i>	<i>Type L,D,S,Lab</i>	<i>Hours/ Credits week</i>		<i>Remarks</i>
Dr. Beke Dezső	Solid State Physics I.-II.	PF3/31-93	L	2	2x2	2 semesters
Dr. Csarnovics István	Solid State- and Optoelectronics	PF3/332-97	L	2	2	
Dr. Cserhádi Csaba	Electron Microscopy	PF3/316-93	L	2	2	
Dr. Csík Attila	X-ray related technics for solid state studies	PF3/346-14	L+Lab	2+1	2	
Dr. Daróczi Lajos	Martensitic transformations	PF3/342-13	L	2	2	
Dr. Erdélyi Zoltán	Diffusion and segregation in nanostructures	PF3/339-02	L	2	2	
Dr. Gulácsi Zsolt	Theoretical Solid State Physics	PF3/32-93	L	2	2	
Dr. Gulácsi Zsolt, Dr. Beke Dezső	Phase Transitions	PF3/35-93	L	2	2x2	2 semesters
Dr. Gulácsi Zsolt	Theory of Magnetism	PF3/320-93	L	2	2	
Dr. Gulácsi Zsolt	Many-Body Calculation Techniques and Applications I.-II.	PF3/323-94	L	2	2x2	2 semesters
Dr. Gulácsi Zsolt	Quantum Phase Transitions	PF3/334-97	L	2	2	
Dr. Gulácsi Zsolt (de Chatel Péter)	Description of Superconductivity	PF3/338-00	L	2	2	
Dr. Gulácsi Zsolt	Many-body systems in periodic potential	PF3/340-08	L	2	2	
Dr. Gulácsi Zsolt,	Theory of Strongly Correlated Systems	PF3/343-14	L	2	2	
Dr. Gulácsi Zsolt	Quantum information and quantum computation	PF3/344-14	L	2	2	
Dr. Kun Ferenc	Computer simulation I.-II.	PF3/327-95	L	2	2x2	2 semesters
Dr. Langer Gábor	Thin Film Deposition Techniques	PF3/317-93	L	2	2	
Dr. Langer Gábor	Thin Films	PF3/324-94	L	2	2	
Dr. Szabó István	Atomic Resolution Microscopy	PF3/329-96	L	2	2	
Dr. Tóth László Zoltán	Micro- and Nanomagnetism I.-II.	PF3/331-97	L	2	2x2	2 semesters

#### IV. Physical Methods in Interdisciplinary Researches program

<i>Teacher/tutor</i>	<i>Course</i>	<i>Code</i>	<i>Type</i> <i>L,D,S,Lab</i>	<i>Hours/ Credits</i> <i>week</i>		<i>Remarks</i>
Dr. Battistig Gábor	Microtechnology	PF4/333-25	L	2	2	
Dr. Csepura György	Radiation Protection	PF4/36-04	L	2	2	
Dr. Csige István	Subsurface Flow	PF4/315-12	L	2	2	
Dr. Erdélyi Róbert	Waves	PF4/320-15	L	2	2	
Dr. Erdélyi Róbert	Solar Magnetohydrodynamics	PF4/321-15	L	2	2	
Dr. Erdélyi Róbert	Advanced Solar Magnetohydrodynamics	PF4/322-16	L	2	2	
Dr. Erdélyi Róbert	Sunpy	PF4/323-16	L	2	2	
Dr. Erdélyi Róbert	Introduction to Plasmaphysics	PF4/324-18	L	2	2	
Dr. Kiss Árpád et al.	Atomic and Nuclear Microanalysis	PF4/31a-93	L	2	2	
Dr. Kiss Árpád et al.	Atomic and Nuclear Microanalysis lab	PF4/31b-93	Lab	4	4	together with L
Dr. Kertész Zsófia, Dr. Molnár Mihály	Atmosphere and climate	PF4/39-09	L	2	2	
Dr. Kertész Zsófia	Atmospheric Aerosol Sampling Procedures and Analysis Techniques Using Ion Beam	PF4/311-12	L	2	2	
Dr. Kun Ferenc	Computer simulation I.-II.	PF4/310-10	L	2	2x2	2 semesters
Dr. Kun Ferenc	Physics of Complex Systems	PF4/313-12	L	2	2	
Dr. Kun Ferenc, ( Dr. Farkas Illés)	Perl Programming and Networks in Computational Biology	PF4/317-14	L	2	2	
Dr. Kun Ferenc, ( Dr. Frank Raichel)	Criticality and Complex Systems	PF4/318-14	L	2	2	
Dr. Kun Ferenc	Complex networks	PF4/325-18	L	2	2	
Dr. Kun Ferenc, ( Dr. Ódor Géza)	Universality classes in non-equilibrium systems	PF4/326-18	L	2	2	
Dr. László Elemér	Fundamentals of atmospheric modelling	PF4/331-24	L	2	2	
Dr. Mason, Nigel John	Planetary Sciences	PF4/330-22	L	2	2	

Dr. Mészáros Sándor	Superconductivity	PF4/328-19	L	2	2
Dr. Molnár Mihály, Dr. Palcsu László	Radioactive dating	PF4/38-09	L	2	2
Dr. Molnár Mihály, (Dr. Timothy Jull)	Geochronology and Paleoclimate	PF4/316-13	L	2	2
Dr. Molnár Mihály (Dr. Ulrich Ott)	Meteorites, the Early Solar System and Nuclear Astrophysics	PF4/319-14	L	2	2
Dr. Nagy Ágnes	Non-linear Phenomena, Chaos	PF4/312-12	L	2	2
Dr. Palcsu László, Dr. Csige István, Dr. Molnár Mihály	Nuclear Environmental Protection	PF4/37-09	L	2	2
Dr. Szabó István	Atomic Resolution Microscopy	PF4/327-18	L	2	2
Dr. Tóth L. Viktor	Space Astronomy	PF4/332-24	L	2	2
Dr. Tőkési Károly	Modelling of collision processes by Monte Carlo technique	PF4/329-20	L	2	2

## V. Particle Physics program

<i>Teacher/tutor</i>	<i>Course</i>	<i>Code</i>	<i>Type L,D,S,Lab</i>	<i>Hours/ Credits week</i>		<i>Remarks</i>
Dr. Angeli István, Dr. Rajta István	High Energy Accelerators I.-II.	PF5/31-95	L	2	2x2	2 semesters
Dr. Cseh József	Symmetries in Two-Body and Many-Body Systems	PF5/321-97	L	2	2	
Dr. Dávid Gábor , Dr. Nagy Sándor	Modeling, Simulation, Analysis in Experimental Particle Physics I.-III.	PF5/33-95	L	2	3x2	3 semesters
Dr. Dávid Gábor	Data Acquisition, Triggering and Online Monitoring	PF5/331-10	L	2	2	
Dr. Fülöp Zsolt, ( Dr. Kai Zuber)	Neutrino Physics	PF5/340-18	L	2	2	
Dr. Horváth Dezső	The Standard Model and its experimental tests I-II.	PF5/326-00	L+Lab	2+2	2x(2+1)	2 semesters
Dr. Horváth Dezső	Experimental techniques of particle physics I-II.	PF5/327-01	L	2	2	
Dr. Kardos Ádám	Introduction to Effective Field Theories	PF5/339-18	L	2	2	
Dr. Kardos Ádám	Introduction to FORM programming	PF5/343-22	L	2	2	
Dr. Kovács Tamás György	Statistical field theory	PF5/334-14	L	2	2	
Dr. Kovács Tamás György	Solitons and Instantons	PF5/341-19	L	2	2	
Dr. Kovács Tamás György	Lattice Field Theory 2	PF5/342-19	L	2	2	
Dr. Nagy Sándor	Quantum renormalization group	PF5/338-17	L	2	2	
Dr. Nagy Sándor	Quantum theories of open systems	PF5/344-22	L	2	2	
Dr. Nagy Sándor	Closed time path formalism in physics	PF5/345-22	L	2	2	
Dr. Nándori István	Basics of functional renormalization group method	PF5/337-16	L	2	2	
Dr. Raics Péter	Particle Detectors	PF5/311-95	L	2	2	
Dr. Sailer Kornél	Introduction to Quantum Field Theory	PF5/312-95	L	2	2	
Dr. Sailer Kornél	Symmetries and Symmetry Breaking in	PF5/314-95	L	2	2	

	Quantum Field Theory I.-II.					
Dr. Sailer Kornél	General Relativity	PF5/323-98	L	2	2	
Dr. Sailer Kornél, Dr. Nagy Sándor	Functional renormalization group method	PF5/333-13	L	2	2	
Dr. Sailer Kornél	$T \neq 0$ kvantum-térelmélet	PF5/334-13	L	2	2	
Dr. Sailer Kornél	Cosmology	PF5/335-14	L	2	2	
Dr. Schram Zsolt	Lattice Field Theory	PF5/322-97	L	2	2	
Dr. Schram Zsolt	Variational principles of theoretical physics	PF5/332-11	L	2	2	
Dr. Somogyi Gábor	Methods of computing Feynman integrals	PF5/336-15	L	2	2	
Dr. Trócsányi Zoltán	Standard model	PF5/317-95	L	2	2	
Dr. Trócsányi Zoltán	Grand Unified Theories	PF5/318-95	L	2	2	
Dr. Trócsányi Zoltán	Perturbative Quantum Chromodynamics I.-II.	PF5/320-97	L	2	2x2	2 semesters
Dr. Zilizi Gyula	Electronics in the Experimental Particle Physics	PF5/316-95	L	2	2	

Abbreviations:

L = Lectures

D = Discussion

S = Seminarium

Lab. = Laboratory exercises

# Description of the subjects

## 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

### **Atomic and Molecular Physics**

Some fundamental properties of atoms. Atomic structure and spectra. The hydrogen molecule. Diatomic molecules. Polyatomic molecules. Molecular orbital theory for  $\pi$ -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)

### **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 Pálincás 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  $T \rightarrow 0$  temperatures. Wick theorem. Gell Mann Low theorem. Feynmann diagrams. Correlation functions. The Matsubara 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,  $X^{\square}$  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. Lundqvist, 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. Szépfolussy, 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, (Műszaki 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 Tókési**

**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-Lifshic I Mechhanika

Bjarne Stroustrup: 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)

Donald E. Knuth: A számítógép-programozás művészete 3.

Name of the teacher: **Dr. Károly Tókési**

**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 Stroustrup: 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 Recipes  
Stoyan Gísbért, Takó Galina: Numerikus módszerek I. (Typotex, 2002)  
Donald 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* )

**Modelling of collision processes by Monte Carlo technique****Topics:**

Collisions among energetic particles are fundamental processes of nature having importance in many different areas of research and technology. Recently both classical and quantummechanical theories have been used to calculate cross sections of ion-atom, ion-molecule, ion-solid, collisions for various projectiles. The main difficulty of calculations for atomic, molecular and solid media is that many-body interactions have to be taken into account. Therefore, the success of various approaches to the calculation depends in part on how far a given theory is capable of describing the many-body character of the collision. The classical trajectory Monte Carlo (CTMC) method has been quite successful in dealing with various processes in ion-matter collisions. The CTMC simulation is a non-perturbative method. One of its main advantages is that many-body interactions are exactly taken into account during the collision. This makes the CTMC method useful for the study of two- or more center effects. Moreover in the classical picture it is straightforward to switch on and off the interaction potentials between the individual particles and thereby to study the effects of particular interactions. This method can be simplified and easily extend to electron projectile also. A large number of theoretical description of the spectra of electrons scattered from various samples are available. The analysis is based on very large scale Monte Carlo simulations of the recoil and Doppler effects in reflection and transmission geometries. Besides the experimentally measurable energy distributions the simulations give many partial distributions separately, depending on the number of elastic scatterings (single, and multiple scatterings of different types). Recent advances in the generation of well-characterized femtosecond and sub- femtosecond laser pulses have opened up unprecedented opportunities for the real-time observation of electronic dynamics in atoms, molecules and solids. This field has been coined attosecond chronoscopy or, for short, attosecond physics. Such attosecond chronoscopy allows a novel perspective at a wide range of fundamental photophysical and photochemical processes in the time domain. Attosecond chronoscopy raises fundamental conceptual and theoretical questions as to which novel information becomes accessible and which dynamical processes can be controlled and steered. Understanding and describing the tools of interrogation on an attosecond scale is still in its infancy. Recent theoretical developments in this rapidly developing field based on the Monte Carlo technique will be also the subject of this lecture. Within the lecture, we plan to cover the following topics:

- 1) Brief review: Classical dynamics in the time domain – Monte Carlo methods.
- 2) Classical-quantum correspondence.
- 3) Study the ion-atom collisions by classical trajectory Monte Carlo method.
- 4) Atomic collisions using slow antiprotons.
- 5) Fermi-shuttle type multiple electron scattering in atomic collisions.
- 6) Monte Carlo simulation of electron spectra backscattered elastically from solid sample.
- 7) Interaction of highly charged ions with surfaces - Energy deposition in nanostructured materials.
- 8) Scattering of Highly-Charged Ions at Microcapillaries; Guiding of MeV ion beams.
- 9) Ionization by intense and short electric pulses - classical picture.
- 10) Classical Trajectory Monte Carlo method – „Watching quantum physics in real time”.

- 11) Applications of streaking to atoms, molecules, and solids.
- 12) The "tunneling ionization" and above threshold ionization – semiclassical model.

Name of the teacher: **Dr. András Csehi**

**PF1/328-20**

### **Atoms and molecules in electromagnetic fields**

#### Topics:

The aim of the course is to provide an overview of the basics of modern theoretical methods to investigate atoms and molecules in electromagnetic fields. Fundamental phenomena of light-matter interactions are introduced along with the most important applications and relevant scientific literature. The course constitutes a basis for further atomic- and molecular courses and allows for initiating research work in the field.

1. A brief overview of the basic elements of time-dependent perturbation theory. The dipole approximation.
2. Two-level atom in resonant and nonresonant electric field. The rotating wave approximation. Rabi-oscillation.
3. Adiabatic and nonadiabatic transitions. The Landau-Zener model.
4. Multilevel atoms in electric field: the stimulated Raman adiabatic passage (STIRAP).
5. Open systems: mixed states, the density operator, the Liouville-Neumann equation, decoherence, spontaneous emission.
6. Different flavours of the Stark-effect: linear-, quadratic-, resonant-, nonresonant-, static-, and dynamic Stark-effect.
7. Multiphoton transitions. Two-photon Rabi-frequency, dynamical resonance condition, chirped pulses.
8. Different forms of the Zeeman-effect: weak-, strong-field-, normal-, anomalous Zeeman-effect.
9. Ionization processes: single-photon-, multiphoton-, above-threshold-, tunnel- and direct ionization. The Keldysh-parameter.
10. Applications of femtosecond laser pulses. Pump-probe scheme for the investigation of intramolecular processes.
11. Attosecond pulses. The high-harmonic generation.

#### References

- [1] D.J. Tannor, Introduction to quantum mechanics: a time-dependent perspective, University Science Books, 2006.
- [2] H. Haken, H.C. Wolf, The physics of atoms and quanta, Springer-Verlag Berlin Heidelberg, 2005.
- [3] B.H. Bransden and C.J. Joachain, Physics of atoms and molecules, Prentice Hall-Pearson 2nd edition, 2003.

**Introduction to molecular quantum dynamics**

## Topics:

The aim of the course is to provide an overview of the basics of modern molecular quantum dynamics. Fundamental methods are introduced for the solution of the time-dependent Schrödinger-equation along with the most important physical quantities that can be calculated from the propagated wave function. The scientific literature as well as the most important applications of the field are equally presented.

1. A brief overview of the basic elements of time-dependent quantum mechanics. The superposition principle, vibrational and rotational wave packets. The autocorrelation function and its spectral analysis: the absorption spectrum.
2. Separation of the molecular Schrödinger-equation: the Born-Huang and the Born-Oppenheimer approximations. Potential energy surfaces, nonadiabatic couplings. Adiabatic and diabatic representations. Diabatization methods.
3. Degenerate electronic states. The Neumann-Wigner non-crossing rule. Linear and quadratic degeneracies: conical intersections and Renner-Teller degeneracies. The importance of non-radiative transitions: photostability, molecular devices.
4. Nuclear wave packet propagation methods: the Crank-Nicolson and the split-operator techniques; the time-dependent Hartree and the multiconfigurational time-dependent Hartree methods. Normal coordinates, Jacobi coordinates, basis functions.
5. Physical quantities calculated from the nuclear wave function: electronic state populations, electronic coherence, dissociation probability, kinetic energy release, angular distribution, molecular alignment. Complex absorbing potentials.
6. Control scenarios of intramolecular processes using external electromagnetic fields. Time evolution of the nuclear wave packet on distorted potential energy surfaces. The nonresonant dynamic Stark-effect. The impact of quantum light, squeezed and coherent states.

## References

- [1] H.D. Meyer, F. Gatti, G.A. Worth, Multidimensional Quantum Dynamics, WILEY-VCH Verlag GmbH & Co. KGaA (2009).
- [2] F. Gatti, Molecular Quantum Dynamics, Springer-Verlag Berlin Heidelberg (2014).

**Low energy collisions in molecular astrophysics**

## Topics:

The aim of the course is to give an introduction to the theoretical methods and models used in the low energy collisions of the molecular astrophysics.

The brief overview of the course:

1. Introduction to molecular astrophysics
2. Molecular physics, molecular spectroscopy

3. Molecular structure calculation methods
4. Photochemistry
5. Low-energy electron induced molecular processes
6. Ion-atom, atom-atom, anion-cation collisions.

Bibliography:

1. A. G. G. M. Tielens: Molecular Astrophysics
2. B. H. Bransden, C. J. Joachain: Physics of Atoms and Molecules
3. G. Herzberg: Molecular Spectra and Molecular Structure vol.1
4. M. S. Child: Molecular Collision Theory
5. O. Ingolfsson (ed.): Low-Energy Electrons
6. M. Larsson, A. E. Orel: Dissociative Recombination of Molecular Ions
7. B. H. Bransden and M. R. C. McDowell: Charge Exchange and the Theory of Ion-Atom Collisions

## 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

$U_1(4) \tilde{\wedge} \dots \tilde{\wedge} U_{k-1}(4)$ : rotation-vibration of  $k$ -atomic molecules

$U(4) \tilde{\wedge} U^{ST}(4) \tilde{\wedge} U(3) \dots$ : cluster model of nuclei

$U(6)$ : collective states in nuclei

chaos and dynamical symmetry

hypernuclei

flavour-spin symmetry in the spectrum of hadrons

$U(6) \tilde{\wedge} U(m)$ : 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, Dr. Gábor Kiss**

**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 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, preequilibrium 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. Zoltán Trócsányi**

**PF2/321-94**

### **Standard Model**

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

The main chapters are:

- $SU(2) \times U(1)$  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 $\square$  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  $^{154}\text{Sm}(\alpha, \alpha')$  reaction at  $E_\alpha=10$  and 18 MeV
- 3./ Data reduction and discussion of the results. Determination of the mass quadrupole deformation parameter of  $^{154}\text{Sm}$

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 differentiation 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 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 principal 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. Optimization of the mass resolution of the separator.

Implanting  $^{15}\text{N}$  ions into steel surface. Measuring the depth distribution of  $^{15}\text{N}$  with the  $^{15}\text{N}(\text{p}, \alpha \gamma)^{12}\text{C}$  nuclear reaction. Observation of the yield of the 4.44 MeV  $\gamma$ -radiation of  $^{12}\text{C}$  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)
- (v-p process) (see also below)

Explosive Environments:

- Explosive nucleosynthesis (general consideration)
  - Core-collapse Supernovae:
    - Explosion mechanism
    - Nucleosynthesis (deep layers (r-process, v-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 ( LaBr<sub>3</sub> ), 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 algorithms, 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 algorithms will be discussed, with special attention to the particle identification methods.

**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 excitation, 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

**Meteorites, the Early Solar System and Nuclear Astrophysics**

(See PF4/319-14)

**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

Name of the teacher: **Dr. Zsolt Fülöp**

**PF2/346-20**

### **Nucleosynthesis in Stellar Explosions**

The course is held by Dr. Jordi Jose in English.

1. Nuclear Physics of Stars. Stellar Abundances
2. Classical Novae
3. Thermonuclear Supernovae
4. Type I X-Ray Bursts
5. Other Sites: Stellar Mergers and Core-Collapse Supernovae

Suggested Reading:

- José, J., 2016, Stellar Explosions: Hydrodynamics and Nucleosynthesis, CRC/Taylor and Francis, Boca Raton (Florida, USA), ISBN 9781439853061, 452 pages.
- Iliadis, C., 2015, Nuclear Physics of Stars, 2nd Ed., Wiley-VCH, Weinheim, ISBN 9783527336487, 672 pages.

### **Astrophysics, Astrochemistry and the Origins of Life**

#### Topics

Lecture 1. Introduction – What is life? How did life begin on Earth? and is there life elsewhere in the Solar system and beyond? Presentation of a little history and humanity's reflection on its origins and life beyond Earth. What are the recognized chemical ingredients of life – and why?

Lecture 2 How are the elements formed? Brief review of the formation of Universe. Star formation and star death and birth of elements. Nucleosynthesis:

Lecture 3. Astrochemistry – The Interstellar medium, the cradle of life? Detecting molecules in the ISM (role of ALMA and JWST) How are molecules formed in such regions? How complex are the molecules formed? .

Lecture 4. Development of astrochemical models. What do they predict? How do we validate them? Laboratory studies.

Lecture 5. Planet formation and early life. Survival of prebiotic/ biomolecules in planet forming process. Analysis of asteroids, comets and meteorites. Examples ROSETTA, Hayabusha OSIRIS-REx missions.

Lecture 6. The Early Earth. Development of Earth's atmosphere and its role in life. Emergence of life (fossil records). Do you need a moon for sustaining life?

Lecture 7. Description of various hypotheses that seek to explain the origins of life. Discussion of how to test the validity of such hypotheses. 'Life in the lab' a laboratory programme to explore origins of life.

Lecture 8. Searching for life in our Solar system. What are the best places to search for life in our solar system? Mars. The icy moons of Jupiter. Current and planned missions to Mars and Jupiter.

Lecture 9. Human exploration of space. A brief history of human spaceflight , the ISS, the challenges facing human's living and working in space. Space craft design and operation. Planning a space mission.

Lecture 10. Exoplanets. Detection of exoplanets and observation of their atmospheres. What is a biomarker and how do we look for one?

Lecture 11. Space the final frontier? Where will we be in 2063? Review and projections.

#### Suggested Reading:

From Big Bang to ExoBiology Edited By: Matthew A Malkan (University of California, Los Angeles, USA) and Ben Zuckerman 2nd Edition ISBN: 978-981-120-772-3 (softcover) World Scientific

Astrobiology: An Introduction Kevin W. Plaxco and Michael Gross third edition ISBN: 9781421441290 Johns Hopkins University Press.

The Physics of Interstellar Dust Endrik Krugel ISBN 9780367454654 Routledge Taylor and Francis

About Stars: Their Formation, Evolution, Compositions, Locations and Companions Michael M Woolfson ISBN: 978-1-78634-725-1 (softcover) World Scientific

Rosetta: The Remarkable Story of Europe's Comet Explorer by Peter Bond ISBN 978-3-030-60720-3 Springer

The Solar System in Close-Up by John Wilkinson ISBN 978-3-319-27629-8 Springer

#### Articles

The Future of Origin of Life Research: Bridging Decades-Old Divisions  
<https://www.mdpi.com/2075-1729/10/3/20/htm>

Origins of life by S Leach Advances in Chemical Physics 157:293-313 (2015)  
DOI:10.1002/9781118959602.ch19

Name of the teacher: **Dr. Andrea Ilona Furka**

**PF2/348-22**

#### **Evaluation of novel techniques in radiotherapy**

Radiotherapy, as the fundamental part of Oncology, has undergone a very fast technical development. Novel techniques result longer overall survival time among oncological patients, therefore maintain and support the quality of life is essential. The absorbed dose, the type of delivery and the quality of radiation are crucial to maximize the effectiveness and efficiency of radiotherapy, meanwhile reduce unwanted side-effects. Special dosimetric measurement and high impact quality assurance promote the security of radiotherapy. For a certain patient more radiotherapy plan have to be designed and the radiation oncologist can choose the best one for the case via continuous consultation with medical physicists. Improvement in planning system and self-controlling methods may lead better quality therefore more radical radiotherapy, suggesting favourable clinical outcome

**Calculations of molecular photoabsorption and electron collisions cross sections for astrophysics and other purposes**

The results on a variety of problems covering both collisions and spectroscopy. Electron collision studies using the R-matrix method provide a major source of electron - molecule collision cross sections for problems range from rotational excitation in the interstellar medium to dissociative processes involving radicals in technological plasmas.

An R-matrix theory has also been developed to consider ultra-low energy heavy particle collisions. In this case the inner region is described using codes designed for the studying high resolution molecular spectra.

These spectroscopic (nuclear motion) codes are largely been applied to predict spectra at elevated temperatures of molecules in the atmospheres of exoplanets as part of the ERC-funded ExoMol project. The use of these codes to compute temperature-dependent photodissociation rates will be discussed.

**The origin of the chemical elements**

The course is held by Dr. Zsolt Podolyák.

- Introduction: why it important?
- Nuclear structure: shell model, collective models.
- Nuclear reactions: types, conservation laws.
- Nucleosynthesis processes: burning processes, s, r, p processes.
- Stellar reaction rates: Cross sections, reaction rates for charged particle, neutron and gamma induced reactions. Resonances.
- Nuclear inputs: lifetimes, masses, cross sections, role of isomeric states.
- Experimental techniques: production of radioactive beams.
- Radioactive beam experiments: nuclear reactions.
- Radioactive beam experiments: mass and lifetime measurements. First-forbidden beta decay. Fission.
- Radioactive beam experiments: structure studies in the most exotic nuclei.
- Summary and outlook: future facilities, future of theoretical predictions.

**Suggested Reading:**

Introductory Nuclear Physics by Kenneth S. Krane, ISBN: 0-471-80553-X Wiley

Nuclear Physics of Stars by Christian Iliadis, ISBN: 978-3-527-40602-9 Wiley

Stellar explosions by Jordi José, ISBN: 978-1-4398-5306-1 CRC Press

**Articles**

Nuclear properties for nuclear astrophysics studies by S. Goriely, European Physical Journal A 59, 16 (2023) DOI: 10.1140/epja/s10050-023-00931-x

Origin of the heaviest elements: The rapid neutron-capture process, by J. Cowan, C. Sneden, J. Lawler, A. Aprahamian, M. Wiescher, K. Langanke, G. Martínez-Pinedo, F.K. Thielemann, Rev. Mod. Phys. 93, 015002 (2021) DOI: 10.1103/RevModPhys.93.015002- Introduction, History of neutrinos

Name of the teacher: **Dr. Zsolt Fülöp**

**PF2/351-24**

### **Laboratory Astrophysics: Taking Laboratory to Space**

The course is held by Dr. Murthy S. Gudipati in English.

Introduction:

Laboratory Astrophysics: Experimental and theoretical simulation of astrophysical environments on Earth to understand those phenomena.

How the Laboratory Astrophysics came into existence and how it helps improve our understanding of the Universe? How Humans started understanding Phenomena in Space?

What is Space? Big Bang and the formation of Galaxies, Stars, Planets, the Interstellar Matter, and the context of Life on Earth. How are the elements formed? Brief review of the formation of Universe. Star formation and star death and birth of elements. Nucleosynthesis.

The Big Questions: How Life started on Earth? Are we alone OR is there Life elsewhere in the Universe?

Origin of Life: What are the Unique Conditions that occurred in our Solar System and on Earth?

The Interstellar medium, the cradle of life? Detecting molecules in the ISM (role of ALMA and JWST) How are molecules formed in such regions? How complex are the molecules formed?

Comet and Asteroid Impacts in early Solar System – did they trigger Origin of Life on Earth?

Rosetta Mission: Understanding what comets are made of.

Role of Laboratory Astrophysics in connecting the dots: from Interstellar matter to origin of life on Earth.

Is there Life elsewhere? The Search continues.

What are Ocean Worlds?

What knowledge did we acquire from earlier NASA missions (such as Voyagers, Galileo, and Cassini) about the Ocean Worlds?

Planetary Interiors, Atmospheres, and Magnetic Fields: A comparative Study.

Jupiter and the Galilean Moons. What is unique about Europa? What do we expect from the Europa Clipper Mission?

How Various Instruments on board Europa Clipper Spacecraft are poised to provide science data?

Human exploration of space. A brief history of human spaceflight, the ISS, the challenges facing human's living and working in space. Space craft design and operation. Planning a space mission.

Exoplanets: Looking for Habitable Environments beyond our Solar System.

Detection of exoplanets and observation of their atmospheres.

Laboratory Simulations of Exoplanet Atmospheres.

### Suggested Reading:

- From Big Bang to ExoBiology Edited By: Matthew A Malkan (University of California, Los Angeles, USA) and Ben Zuckerman 2nd Edition ISBN: 978-981-120-772-3 (softcover) World Scientific
- Astrobiology: An Introduction Kevin W. Plaxco and Michael Gross third edition ISBN: 9781421441290 Johns Hopkins University Press.
- The Physics of Interstellar Dust Endrik Krugel ISBN 9780367454654 Routledge Taylor and Francis
- About Stars: Their Formation, Evolution, Compositions, Locations and Companions Michael M Woolfson  
ISBN: 978-1-78634-725-1 (softcover) World Scientific
- Rosetta Mission: The Remarkable Story of Europe's Comet Explorer by Peter Bond ISBN 978-3-030-60720-3 Springer
- The Solar System in Close-Up by John Wilkinson ISBN 978-3-319-27629-8 Springer
- Physics and Chemistry of the Solar System: John S. Lewis (Academic Press)
- Planetary Sciences: Imke de Pater and Jack J. Lissauer (Cambridge University Press)
- Planetary Geology: An Introduction; Claudio Vita-Finzi and Dominic Fortes (Dunedin Press)
  1. Nuclear Physics of Stars. Stellar Abundances
  2. Classical Novae

### 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: Félvezetők 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, Műszaki 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 of 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. 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 homogeneity; 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. Csaba Cserhádi**

**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, Orientation 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. Radnóczy: 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. 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. 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. 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. 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. Csarnovics István**

**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-, magneto-optical 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 as 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**

**PF3/338-00**

### **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. Zoltán Erdélyi**

**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 to 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. Cserhádi, 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. Lajos Daróczy**

**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 Ansatz 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 machine, 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 algorithms, Deutsch-Jozsa, Simon, Schor, Grover; Quantum cryptography, quantum error-corrections; Cloning, entanglement, superdense coding, teleportation; Decoherence and quantum hardware.

Name of the teacher: **Dr. Attila Csík**

**PF3/346-14**

### **X-ray related techniques 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. 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”) radioactive matter in practice. Measure of thickness, level, thick e.g.. Diagnostic and therapy in medical.

Cosmic ray. Spaceship, in particular for astronauts. 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:**

- 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)
- 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, SF<sub>6</sub>, 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* (Academic 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., Swetnam, T.W. (eds.) 1994: *Tree rings, Environment and Humanity* (Radiocarbon, Tucson)
6. Matsuda, J.(ed.)1994: *Noble Gas Geochemistry and Cosmochemistry* (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 course 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 and 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 CO<sub>2</sub>, its measuring techniques (<sup>14</sup>C method, CO method, etc.) The sources of CH<sub>4</sub> 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 11<sup>th</sup> 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 multifractals.

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. 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, Fractals 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. Transport of pollutants. Gas flow in the vadose zone. Transport 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 Multiphysics 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](http://www.sunpy.org)) is a modern, open-source software package written in Python. It is a high-level computing language and software tool, indispensable 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. Newman, 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**)

Name of the teacher: **Dr. Károly Tókési**

**PF4/329-20**

**Modelling of collision processes by Monte Carlo technique**  
( See: **PF1/327-20**)

Name of the teacher: **Dr. Nigel John Mason**

**PF4/330-22**

**Planetary Sciences**

Understanding the formation and evolution of planets is one of the most fascinating topics of modern astronomy. The detection of planets around other stars (exo-planets) was a paradigm shift in our understanding of the of our own solar system within the wider astronomical context and the universe and deservedly won the Nobel prize in 2019. This course will review the physics of planet formation and its coupling with parent stars; the different types of planets from gas giants, icy worlds and 'Earths', the evolution and structure of planetary atmospheres, the role of orbiting moons and interaction between planets and the stellar wind and cosmic radiation. Using the solar system as an exemple of the variety of planets that can be formed, from ocean worlds to gas giants, the course will explore the characteristics of different planets and their causality with the opportunity to become habitable. Throughout the course examples and data from past present missions will be presented and we will look forward to the next decade when a suite of space missions will provide new insights into planetary processes. The course will conclude with lectures on humanity's own opportunity to visit new worlds and the physics that must be addressed if habitations on our own moon and Mars is to become possible.

**Outline**

Introduction to Solar system and Exo-planets 2 lectures

Planet formation - 2 lectures

Planetary evolution - 2 lectures.  
Moons - 2 lectures  
Radiation interactions and space weather - 2 lectures  
Life and habitability - 2 lectures  
Human exploration - 2 lectures

Name of the teacher: **Dr. Elemér László**

**PF4/331-24**

### **Fundamentals of atmospheric modelling**

Numerical weather and coupled models. The atmospheric governing equations. The shape of the hydro-thermodynamic equation system, closing hypotheses. Classification principles of atmospheric and coupled numerical models. Fluid mechanics models. Diffusion models - atmospheric pollutant distribution. The numerical model as a research and development tool.

References:

- Gyöngyösi, A. Z. Weidinger, T. (Szerk), 2013: **Alkalmazott számszerű előrejelzés – numerikus időjárási és csatolt modellek a gyakorlatban**, ELTE jegyzet, Budapest
- Jacobson, M. Z., 2005: **Fundamentals in Atmospheric Modeling**, (2nd edition), CUP Washington, W. M. and Parkinson, C. L. 1986: **An introduction to three-dimensional climate modeling**, University Science Books, Oxford

Az oktató neve: **Dr. L. Viktor Tóth**

**PF4/332-24**

### **Space Astronomy**

The lecturer points out the social and scientific connections of space research and the significant Hungarian participation during the presentation of the early history of space exploration and the most important personalities. We learn about the use of spacecrafts in astronomical research (expanding the frequency range, increasing resolution, in-situ measurements). During the semester, we will learn about the phases of space projects and the basics of the related logistical and technical foundations. We discuss the key events in the history of space astronomy. Particular emphasis is given on the exploration of the Solar System, pointing out the role of spacecrafts observing the Sun and visiting the planets. We get to know the basic elements of the terrestrial technical and human infrastructure supporting space programs, as well as the structure of the worldwide leading institutions (NASA, ESA, Roskosmos, JAXA) that organize them. We review the typical spacecraft trajectories, as well as the tools and methods used for their launch and trajectory modification. We give examples of major space astronomical results beyond the solar system.

### **Microtechnology**

The course covers modern micro- and nanotechnology processes and related testing methods in detail.

- Materials and auxiliary materials used in micro- and nanoelectronics, the properties of the required manufacturing environment
- Physical and chemical thin film deposition technologies
- Lithography in the nanometer range
- Doping and ion beam techniques
- 3D structure formation, physical, chemical and plasma etching processes
- High-temperature processes
- Encapsulation, packaging
- Surface and thin film qualification processes
- Applications in semiconductor integrated circuit manufacturing, MEMS and NEMS systems, sensors, microfluidics, biomedical sensors
- Outlook for non-electronic applications: surface treatments, coatings, surface and interface modifications, tribological applications

#### Literature:

- Robert Doering, Yoshio Nishi (Eds.), Handbook of Semiconductor Manufacturing Technology, ISBN-13 978-1-57444-675-3, CRC Press (2008)
- Bharat Bhushan (Ed.), Handbook of Nanotechnology, ISBN 3-540-01218-4, Springer Verlag Berlin Heidelberg New York, (2003) A kurzus során a modern mikro- és nanotechnológiai eljárások és a kapcsolódó vizsgálati módszerek részletes tárgyalására kerül sor.

## **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 Chromodynamics I.-II.**

#### **Part I.**

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

- The QCD Lagrangian
- 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 divergences:
  - 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 topics: causal 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  $U(1)$  = electromagnetic interaction

Local  $SU(3)$  = strong interaction

Local  $SU(2) \oplus U(1)$  = 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 detectors. 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 detectors, 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. Ampère'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 physics
- 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). Homogeneous and isotropic Universe (Robertson-Walker-metric, Friedmann-equations and their solutions, horizons, conform diagrams, redshift, cosmologic parameter, deceleration 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-perturbatively.

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** )

Name of the teacher: **Dr. Tamás György Kovács**

**PF5/341-19**

### **Solitons and Instantons**

#### Topics

- 1) Classical solitons and their characterization with topological indices
- 2) Solitons in the sine/Gordon model
- 3) Monopoles (general introduction)
- 4) 't Hooft-Polyakov monopoles
- 5) Instantons (general introduction)
- 6) Euclidean Yang-Mills configurations, Euclidean instantons
- 7) Instantons in other field theories
- 8) Quantization of static solutions
- 9) Quantization with the path integral, the WKB method in field theories

Reading: Rajaraman, Solitons and instantons (Elsevier, 1989)

Name of the teacher: **Dr. Tamás György Kovács**

**PF5/342-19**

### **Lattice Field Theory 2**

#### Topics

- 1) Lattice gauge theory (parallel transport, Wilson action)
- 2) Strong coupling expansion (group character expansion, evaluation of graphs, expansion of the free energy)
- 3) Strong coupling expansion of the Wilson loop, static potential, quark confinement.
- 4) Fermions on the lattice (naive fermions, doubling, Nielsen-Ninomiya theorem)
- 5) Wilson and staggered discretization, staggered rooting trick
- 6) Chiral fermions (Ginsparg-Wilson relation, overlap, chiral symmetry on the lattice, index theorem)
- 7) Algorithms (Markov chains, detailed balance, local algorithms, molecular dynamics)

Reading: Montvay, Münster, Quantum Fields on a Lattice (CUP, 1994).

Name of the teacher: **Dr. Ádám Kardos**

**PF5/343-22**

### **Introduction to FORM programming**

#### Topics

The purpose of the course is to introduce students to the FORM computer algebra system. During the course several aspects of programming in FORM will be covered. At the beginning FORM is compared other computer algebra systems. The basic structure of a FORM program is introduced with fundamental variables, local expressions and print out facilities. To progress towards more complicated calculations pre-processor variables, built-in functions are introduced with structural programming constructs. Using practical

calculations manipulations with n-dimensional vectors and tensors are covered. The notion of dollar variables are introduced. Using examples from particle physics more recent features of FORM are introduced and demonstrated through calculation of squared matrix elements and Feynman parameter integrals commonly used in quantum field theory.

Suggested reading:

J. A. M. Vermaseren et al.: FORM Reference Manual

Name of the teacher: **Dr. Sándor Nagy**

**PF5/344-22**

### **Quantum theories of open systems**

Topics

The limitation of the application of closed systems, the roles of open systems and the environment in physics. The study of open systems in classical physics, effective theories. The system of harmonic oscillators as an example. The role of the closed time path (CTP) formalism in the treatment of open systems. The Green's functions in CTP formalism. Path integral and influence functional, the Feynman-Vernon method. The CTP propagator and its inverse, the types of the CTP Feynman graphs. The application of the functional renormalization group method for open quantum systems. The role of the nonlocal interactions. The entanglement of the system and environment modes.

Ajánlott irodalom:

- János Polonyi, Dissipation and decoherence by a homogeneous ideal gas, Phys. Rev. A92, 042111 (2015).
- Heinz-Peter Breuer, Francesco Petruccione, The Theory of Open Quantum Systems, Oxford University Press (2002).

Name of the teacher: **Dr. Sándor Nagy**

**PF5/345-22**

### **Closed time path formalism in physics**

Topics

Duplication of variables, introduction of the two time axes. Interaction between the time axes. The usage of the closed time path (CTP) formalism in classical mechanics, the description effective theories. The CTP generating functional, CTP symmetries. The form of the CTP propagator, near field, far field functions for zero and finite temperature. The connection between the system-environment interaction and the nonlocal interactions. Conservation laws, Noether theorem. The appearance of irreversibility and decoherence in CTP formalism. Generalized fluctuation-dissipation theorem.

Ajánlott irodalom:

- János Polonyi, Quantum-classical crossover in electrodynamics, Phys. Rev. D74, 065014 (2006).
- Esteban A. Calzetta, Bei-Lok B. Hu, Nonequilibrium Quantum Field Theory, Cambridge University Press (2008).