Module No.: physics70c
Credit Points (CP): 3-7
Category: Elective
Semester: 1.-2.

Fachgruppe Physik und Astronomie Universität Bonn

Module: Elective Advanced Lectures: Theoretical Physics

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Selected courses from catalogue type "T" (Theoretical)	see catalogue	5-7	see catalogue	150-210 hrs	WT/ST
2.	Also possible classes from M.Sc. in Astrophysics					

Requirements for Participation:
none

Form of Examination:
see with the course

Content:
Advanced lectures in theoretical physics

Aims/Skills:
Preparation for Master's Thesis work; broadening of scientific knowledge

Course achievement/Criteria for awarding cp's:
see with the course

Length of Module: 1 or 2 semester

Maximum Number of Participants: ca. 100

Registration Procedure:
s. https://basis.uni-bonn.de u. http://bamawww.physik.uni-bonn.de

Note: The student must achieve at least 18 CP out of all 4 Elective Advanced Modules

Modules:	physics70a	**Elective Advanced Lectures: Experimental Physics**
	physics70c	**Elective Advanced Lectures: Theoretical Physics**

Course: Ultracold Atomic Gases (E/T)

Course No.: physics742

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+1	6	WT

Requirements for Participation:

Preparation:
Quantum Mechanics

Form of Testing and Examination:
Requirements for the examination (written or oral): successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
This lecture discusses both the experimental and theoretical concepts of ultra-cold atomic gases.

Contents of the Course:
Almost hundred years ago, in 1924, A. Einstein and S.N. Bose predicted the existence of a new state of matter, the so-called Bose-Einstein condensate. It took 70 years to successfully realize this macroscopic quantum state in the lab using ultracold atomic gases (Nobel prize 2001). The main challenge was to achieve cooling to Nanokelvin temperatures, the coolest temperatures ever reached by mankind. Nowadays, ultracold gases are exciting systems to study a broad range of quantum phenomena. These phenomena range from the direct observation of quantum matter waves and superfluidity over the creation of artificial crystal structures as analogous to solids, to the realization of complex quantum phase transitions of interacting atoms, e.g. the formation of a bosonic Mott-insulator or the BCS superconducting state for Fermions. In this lecture we will discuss both the experimental and theoretical concepts of ultra-cold atomic gases.

Outline: Introduction and revision of basic concepts, Fundamentals of atom-laser interaction
Laser cooling & trapping, Bose-Einstein condensation of atomic gases. Dynamics of Bose-Einstein condensates
Optical lattices: strongly interacting atomic gases and quantum phase transitions
The crossover of Fermi-gases between a BCS superconducting state and a Bose-Einstein condensate of molecules.

Recommended Literature:
C. J. Pethick and H. Smith, Bose-Einstein Condensation in Dilute Gases (Cambridge University Press)

Modules:

ECThPhysics **Elective Courses Theoretical Physics**
physics70c **Elective Advanced Lectures: Theoretical Physics**

Course: Group Theory (T)

Course No.: physics751

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT

Requirements for Participation:

Preparation:
physik421 (Quantum Mechanics)

Form of Testing and Examination:
Requirements for the examination (written): successful work with the

Length of Course:
1 semester

Aims of the Course:
Acquisition of mathematical foundations of group theory with regard to applications in theoretical physics

Contents of the Course:
Mathematical foundations:
Finite groups, Lie groups and Lie algebras, highest weight representations, classification of simple Lie algebras, Dynkin diagrams, tensor products and Young tableaux, spinors, Clifford algebras, Lie super algebras

Recommended Literature:
B. G. Wybourne; Classical Groups for Physicists (J. Wiley & Sons 1974)
H. Georgi; Lie Algebras in Particle Physics (Perseus Books 2. Aufl. 1999)
W. Fulton, J. Harris; Representation Theory (Springer, New York 1991)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: universitätbonn Superstring Theory (T)

Course No.: physics752

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT

Requirements for Participation:

Preparation:
Quantum Field Theory (physics755)
Group Theory (physics751)
Advanced Theoretical Physics (physics607) / Advanced Quantum Field Theory (physics7501)
Theoretical Particle Physics (physics615)

Form of Testing and Examination:
Requirements for the examination (written): successful work with the

Length of Course:
1 semester

Aims of the Course:
Survey of modern string theory as a candidate of a unified theory in regard to current research

Contents of the Course:
Bosonic String Theory, Elementary Conformal Field Theory
Kaluza-Klein Theory
Crash Course in Supersymmetry
Superstring Theory
Heterotic String Theory
Compactification, Duality, D-Branes
M-Theory

Recommended Literature:
D. Lüst, S. Theisen; Lectures on String Theory (Springer, New York 1989)
S. Förste; Strings, Branes and Extra Dimensions, Fortsch. Phys. 50 (2002) 221, hep-th/0110055
C. Johnson, D-Brane Primer (Cambridge University Press 2003)
M. Green, J. Schwarz, E. Witten; Superstring Theory I & II (Cambridge University Press 1988)
H.P. Nilles, Supersymmetry and phenomenology (Phys. Reps. 110 C (1984) 1)
J. Polchinski; String Theory I & II (Cambridge University Press 2005)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Theoretical Particle Astrophysics (T)

Course No.: physics753

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation:

Preparation:
General Relativity and Cosmology (physics754)
Quantum Field Theory (physics755)
Theoretical Particle Physics (physics615)

Form of Testing and Examination:
Requirements for the examination (written): successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
Introduction to the current status at the interface of particle physics and cosmology

Contents of the Course:
Topics on the interface of cosmology and particle physics:
Inflation and the cosmic microwave background;
baryogenisis,
Dark Matter,
nucleosynthesis
the cosmology and astrophysics of neutrinos

Recommended Literature:
J. Peacock, Cosmological Physics (Cambridge University Press 1998)
E. Kolb, M. Turner; The Early Universe (Addison Wesley 1990)

Modules:		
	ECThPhysics	**Elective Courses Theoretical Physics**
	physics70c	**Elective Advanced Lectures: Theoretical Physics**

Course: General Relativity and Cosmology (T)

Course No.: physics754

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation:

Preparation:
physik221 and physik321 (Theoretical Physics I and II)
Differential geometry

Form of Testing and Examination:
Requirements for the examination (written): successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
Understanding the general theory of relativity and its cosmological implications

Contents of the Course:
Relativity principle
Gravitation in relativistic mechanics
Curvilineal coordinates
Curvature and energy-momentum tensor
Einstein-Hilbert action and the equations of the gravitational field
Black holes
Gravitational waves
Time evolution of the universe
Friedmann-Robertson-Walker solutions

Recommended Literature:
S.Weinberg; Gravitation and Cosmology (J. Wiley & Sons 1972)
R. Sexl: Gravitation und Kosmologie, Eine Einführung in die Allgemeine Relativitätstheorie (Spektrum Akadem. Verlag 5. Aufl 2002)
L.D. Landau, E.M. Lifschitz; Course of Theoretical Physics Vol.2: Classical field theory (Butterworth-Heinemann 1995), also available in German from publisher Harry Deutsch

Modules:

ECThPhysics **Elective Courses Theoretical Physics**
physics70c **Elective Advanced Lectures: Theoretical Physics**

Course: universitätbonn Quantum Field Theory (T)

Course No.: physics755

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation:

Preparation:
Advanced quantum theory (physics606)

Form of Testing and Examination:
Requirements for the examination (written): successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
Understanding quantum field theoretical methods, ability to compute processes in quantum electrodynamics (QED) and many particle systems

Contents of the Course:
Classical field theory
Quantization of free fields
Path integral formalism
Perturbation theory
Methods of regularization: Pauli-Villars, dimensional
Renormalizability
Computation of Feynman diagrams
Transition amplitudes in QED
Applications in many particle systems

Recommended Literature:
N. N. Bogoliubov, D.V. Shirkov; Introduction to the theory of quantized fields (J. Wiley & Sons 1959)
M. Kaku, Quantum Field Theory (Oxford University Press 1993)
M. E. Peskin, D.V. Schroeder; An Introduction to Quantum Field Theory (Harper Collins Publ. 1995)
L. H. Ryder; Quantum Field Theory (Cambridge University Press 1996)
S. Weinberg; The Quantum Theory of Fields (Cambridge University Press 1995)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Critical Phenomena (T)

Course No.: physics756

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation:

Preparation:
Advanced quantum theory (physics606)
Theoretical condensed matter physics (physics617)

Form of Testing and Examination:
Requirements for the examination (written): successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
Acquisition of important methods to treat critical phenomena

Contents of the Course:
Mean Field Approximation and its Improvements
Critical Behaviour at Surfaces
Statistics of Polymers
Concept of a Tomonaga-Luttinger Fluid
Random Systems
Phase Transitions, Critical Exponents
Scale Behaviour, Conformal Field Theory
Special Topics of Nanoscopic Physics

Recommended Literature:
J. Cardy, Scaling and Renormalization in Statistical Physics (Cambridge University Press, 1996)
A. O. Gogolin, A. A. Nersesyan, A.N.Tsvelik; Bosonisation and strongly correlated systems (Cambridge University Press, 1998)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Effective Field Theory (T)

Course No.: physics757

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT/ST

Requirements for Participation:

Preparation:
Advanced quantum theory (physics606)
Quantum Field Theory (physics755)

Form of Testing and Examination:
Requirements for the examination (written): successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
Understanding basic properties and construction of Effective Field Theories, ability to perform calculations in Effective Field Theories

Contents of the Course:
Scales in physical systems, naturalness
Effective Quantum Field Theories
Renormalization Group, Universality
Construction of Effective Field Theories
Applications: effective field theories for physics beyond the Standard Model, heavy quarks, chiral dynamics, low-energy nuclear physics, ultracold atoms

Recommended Literature:
S. Weinberg; The Quantum Theory of Fields (Cambridge University Press 1995)
J.F. Donoghue et al.; Dynamics of the Standard Model (Cambridge University Press 1994)
A.V. Manohar, M.B. Wise; Heavy Quark Physics (Cambridge University Press 2007)
P. Ramond, Journeys Beyond The Standard Model (Westview Press 2003)
D.B. Kaplan, Effective Field Theories (arXiv:nucl-th/9506035)
E. Braaten, H.-W. Hammer; Universality in Few-Body Systems with Large Scattering Length (Phys. Rep. 428 (2006) 259)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: universitätbonn Quantum Chromodynamics (T)

Course No.: physics758

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT/ST

Requirements for Participation:

Preparation:
Advanced quantum theory (physics606)
Quantum Field Theory (physics755)

Form of Testing and Examination:
Requirements for the examination (written): successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
Understanding basic properties of Quantum Chromodynamics, ability to compute strong interaction processes

Contents of the Course:
Quantum Chromodynamics as a Quantum Field Theory
Perturbative Quantum Chromodynamics
Topological objects: instantons etc.
Large N expansion
Lattice Quantum Chromodynamics
Effective Field Theories of Quantum Chromodynamics
Flavor physics (light and heavy quarks)

Recommended Literature:
S. Weinberg; The Quantum Theory of Fields (Cambridge University Press 1995)
M.E. Peskin, D.V. Schroeder; An Introduction to Quantum Field Theory (Westview Press 1995)
F.J. Yndurain; The Theory of Quark and Gluon Interactions (Springer 2006)
J.F. Donoghue et al.; Dynamics of the Standard Model (Cambridge University Press 1994)
E. Leader and E. Predazzi; An Introduction to Gauge Theories and Modern Particle Physics (Cambridge University Press 1996)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Quantum Field Theory for Condensed Matter Physics (T)

Course No.: physics759a

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT

Requirements for Participation:
Quantum Mechanics (physik421)
Thermodynamics and Statistical Physics (physik521)

Preparation:
Elementary condensed matter physics (physik411 or similar)

Form of Testing and Examination:
Requirements for the examination (written or oral): successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
Knowledge of quantum field theory of interacting many-body systems at finite temperature
Knowledge of quantum field theory for non-equilibrium systems
Ability to construct and evaluate perturbation theory using Feynman diagrams
Basic understanding of problems of open quantum systems

Contents of the Course:
Fock space and occupation-number representation for bosons and fermions (if not yet familiar)
Elementary linear response theory
Quantum field theory at finite temperature: functional integral fomulation
Green's functions: analytical properties and their relation to observable quantities
Perturbation theory in thermodynamic equilibrium: Feynman diagrams, Matsubara technique
Kondo effect and renormalization group
Quantum field theory away from thermodynamic equilibrium: Schwinger-Keldysh functional integral
Perturbation theory away from equilibrium: Keldysh technique
Open and driven-dissipative quantum systems: Lindblad formalism

Recommended Literature:
A. Kamenev, Field Theory of Non-Equilibrium Systems, 2nd edition, Cambridge University Press (2023).
G. Stefanucci, R. van Leeuwen, Nonequilibrium Many-Body Theory of Quantum Systems, A Modern Introduction, Cambridge University Press (2013).
H.-P. Breuer, F. Petruccione, The Theory of Open Quantum Systems, Oxford University Press (2002, reprinted 2010).
P. Coleman, Introduction to Many-Body Physics, Cambridge University Press (2015, reprinted 2017).

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Advanced Quantum Field Theory for Condensed Matter Physics (T)

Course No.: physics759b

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation:
Quantum Field Theory for Condensed Matter Physics (physics759a)

Preparation:
Special interest in theoretical condensed matter physics and mathematical physics

Form of Testing and Examination:
Requirements for the examination (written or oral): successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
Knowledge of advanced methods for evaluating quantum field theories
Knowledge of advanced models of quantum many-body systems

Contents of the Course:
Selected topics of modern theoretical condensed matter field theory, for example:
Formalism of generating functionals
Luttinger-Ward identities and conserving approximations
Bosonization
Dynamical Mean-Field Theory (DMFT)
Disordered systems and Anderson localization
Applications of field-theoretic methods to specific models

Recommended Literature:
A. Kamenev, Field Theory of Non-Equilibrium Systems, 2nd edition, Cambridge University Press (2023).
G. Stefanucci, R. van Leeuwen, Nonequilibrium Many-Body Theory of Quantum Systems, A Modern Introduction, Cambridge University Press (2013).
P. Coleman, Introduction to Many-Body Physics, Cambridge University Press (2015, reprinted 2017).
Th. Giamarchi, Quantum Physics in One Dimension, Oxford University Press (2004).

Modules:

ECThPhysics **Elective Courses Theoretical Physics**
physics70c **Elective Advanced Lectures: Theoretical Physics**

Course: universitätbonn Computational Physics (T)

Course No.: physics760

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises and project work	English	2+2+1	7	WT/ST

Requirements for Participation:
Knowledge of a modern programming language (like C, C++)

Preparation:
Theoretical courses at the Bachelor degree level

Form of Testing and Examination:
successful participation in exercises,
presentation of an independently completed project

Length of Course:
1 semester

Aims of the Course:
ability to apply modern computational methods for solving physics problems

Contents of the Course:
Statistical Models, Likelihood, Bayesian and Bootstrap Methods
Random Variable Generation
Stochastic Processes
Monte-Carlo methods
Markov-Chain Monte-Carlo

Recommended Literature:
W.H. Press et al.: Numerical Recipes in C (Cambridge University Press)
http://library.lanl.gov/numerical/index.html
C.P. Robert and G. Casella: Monte Carlo Statistical Methods (Springer 2004)
Tao Pang: An Introduction to Computational Physics (Cambridge University Press)
Vesely, Franz J.: Computational Physics: An Introduction (Springer)
Binder, Kurt and Heermann, Dieter W.: Monte Carlo Simulation in Statistical Physics (Springer)
Fehske, H.; Schneider, R.; Weisse, A.: Computational Many-Particle Physics (Springer)

Module:	**Elective Advanced Lectures: Theoretical Physics**
Module No.: physics70c	

Course: Supersymmetry (T)

Course No.: physics761

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+1	6	WT/ST

Requirements for Participation:
Quantum Field Theory I

Preparation:

Form of Testing and Examination:
Individual Oral Examinations

Length of Course:
1 semester

Aims of the Course:
Teach the students the basics of supersymmetric field theory and how it can be tested at the LHC.

Contents of the Course:
Superfields; Supersymmetric Lagrangians; MSSM; Testing the MSSM at the LHC

Recommended Literature:
Theory and phenomenology of sparticles: An account of four-dimensional N=1 supersymmetry in high energy physics.
M. Drees, (Bonn U.) , R. Godbole, (Bangalore, Indian Inst. Sci.) , P. Roy, (Tata Inst.) . 2004. 555pp.
Hackensack, USA: World Scientific (2004) 555 p.

Weak scale supersymmetry: From superfields to scattering events.
H. Baer, (Florida State U.) , X. Tata, (Hawaii U.) . 2006. 537pp.
Cambridge, UK: Univ. Pr. (2006) 537 p.

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Transport in mesoscopic systems (T)

Course No.: physics762

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	5	WT/ST

Requirements for Participation:

Preparation:
Classical mechanics
Elementary thermodynamics and statistical physics (physik521)
Advanced quantum theory (physics606)
Introductory theoretical condensed matter physics (physics617)

Form of Testing and Examination:
Requirements for the examination (written or oral); successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
Understanding essential transport phenomena in solids and mesoscopic systems
Acquisition of important methods for treating transport problems

Contents of the Course:
Linear response theory
Disordered and ballistic systems
Semiclassical approximation
Introduction to quantum chaos theory, chaos and integrability in classical and quantum mechanics
Elements of random matrix theory
Specific problems of mesoscopic transport (weak localization, universal conductance fluctuations, shot noise, spin-dependent transport, etc.)
Quantum field theory away from thermodynamic equilibrium

Recommended Literature:
K. Richter, Semiclassical Theory of Mesoscopic Quantum Systems, Springer, 2000 (http://www.physik.uni-regensburg.de/forschung/richter/richter/pages/research/springer-tracts-161.pdf)
M. Brack, R. K. Bhaduri, Semiclassical Physics, Westview Press, 2003
S. Datta, Electronic Transport in Mesoscopic Systems, Cambrige University Press, 1995
M. C. Gutzwiller, Chaos in Classical and Quantum Mechanics, Springer, New York, 1990
F. Haake, Quantum signatures of chaos, Springer, 2001
M. L. Mehta, Random matrices, Elsevier, 2004
J. Imry, Introduction to mesoscopic physics, Oxford University Press
Th. Giamarchi, The physics of one-dimensional systems, Oxford University Press

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Advanced Topics in String Theory (T)

Course No.: physics763

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation:

Preparation:
Quantum Field Theory (physics755)
Group Theory (physics751)
Advanced Theoretical Physics (physics607) / Advanced Quantum Field Theory (physics7501)
Theoretical Particle Physics (physics615)
Superstring Theory (physics752)

Form of Testing and Examination:
active participation in exercises, written examination

Length of Course:
1 semester

Aims of the Course:
Detailed discussion of modern string theory as a candidate of a unified theory in regard to current research

Contents of the Course:
Realistic compactifications
Interactions
Effective actions
Heterotic strings in four dimensions
Intersecting D-branes

Recommended Literature:
D. Lüst, S. Theisen: Lectures on String Theory (Springer, New York 1989)
S. Förste: Strings, Branes and Extra Dimensions, Fortsch. Phys. 50 (2002) 221, hep-th/0110055
C. Johnson: D-Brane Primer (Cambridge University Press 2003)
M. Green, J. Schwarz, E. Witten: Superstring Theory I & II (Cambridge University Press 1988)
H.P. Nilles: Supersymmetry and Phenomenology (Phys. Reps. 110C (1984)1)
J. Polchinski: String Theory I & II (Cambridge University Press 2005)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Advanced Topics in Field and String Theory (T)

Course No.: physics764

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation:
Prerequisite knowledge of Quantum Field Theory, Superstring Theory, and General Relativity is helpful.

Preparation:
Quantum Field Theory (physics755)
Advanced Theoretical Physics (physics607) / Advanced Quantum Field Theory (physics7501)
Superstring Theory (physics752)

Form of Testing and Examination:
active participation in exercises, oral or written examination

Length of Course:
1 semester

Aims of the Course:
An introduction into modern topics in Mathematical High Energy Physics in regard to current research areas

Contents of the Course:
String and Supergravity Theories in various dimensions
Dualities in Field Theory and String Theory
Topological Field Theories and Topological Strings
Large N dualities and integrability

Recommended Literature:
Selected review articles an arXiv.org [hep-th]
J. Polchinski: String Theory I & II
S. Weinberg: Quantum Theory of Fields

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Advanced Topics in Quantum Field Theory (T)

Course No.: physics765

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST

Requirements for Participation:
Prerequisite knowledge of Quantum Field Theory

Preparation:
Quantum Field Theory (physics755)
Advanced Theoretical Physics (physics607) / Advanced Quantum Field Theory (physics7501)

Form of Testing and Examination:
active participation in exercises, oral or written examination

Length of Course:
1 semester

Aims of the Course:
Covers advanced topics in Quantum Field Theory that are relevant for current developments in the field.

Contents of the Course:
TBA

Recommended Literature:
Selected articles on arXiv.org [hep-th]
TBA

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Physics of Higgs Bosons (T)

Course No.: physics766

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT

Requirements for Participation:

Preparation:
Theoretical Particle Physics (physics615)

Form of Testing and Examination:
Requirement for the examination (written or oral): successful participation in the exercises

Length of Course:
1 semester

Aims of the Course:
Understanding the physics of electroweak symmetry breaking, and the interpretations of the recently discovered signals for the existence of a Higgs boson

Contents of the Course:
Spontaneous symmetry breaking
The Higgs mechanism
The Higgs boson of the Standard Model
Experimental situation
Extended Higgs sectors
Precision calculations

Recommended Literature:
J. Gunion, H.E. Haber, G.L. Kane and S. Dawson: The Higgs Hunter's Guide (Frontiers of Physics, 2000)
A. Djouadi: Anatomy of Electroweak Symmetry Breaking I (Phys. Rep. 457 (2008) 1, hep-ph/0503173)
A. Djouadi: Anatomy of Electroweak Symmetry Breaking II (Phys. Rep. 459 (2008) 1, hep-ph/0504090)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Computational Methods in Condensed Matter Theory (T)

Course No.: physics767

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT/ST

Requirements for Participation:

Preparation:
Quantum Field Theory (physics755)
Advanced Theoretical Physics (physics607) / Advanced Quantum Field Theory (physics7501)
Advanced Theoretical Condensed Matter Physics (physics638)

Form of Testing and Examination:
Active participation in exercises, written examination

Length of Course:
1 semester

Aims of the Course:
Detailed discussion of computational tools in modern condensed matter theory

Contents of the Course:
Exact Diagonalization (ED)
Quantum Monte Carlo (QMC)
(Stochastic) Series expansion (SSE)
Density Matrix Renormalization (DMRG)
Dynamical Mean Field theory (DMFT)

Recommended Literature:
will be given in the lecture

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: General Relativity for Experimentalists (T)

Course No.: physics768

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT/ST

Requirements for Participation:

Preparation:
Theoretische Physik I & II, Analysis I & II

Form of Testing and Examination:
Weekly homework sets (50% required), Final exam

Length of Course:
1 semester

Aims of the Course:
The students shall learn the basics of general relativity and be able to apply it to applications such as experimental tests of GR, GPS, astrophysical objects and simple issues in cosmology.

Contents of the Course:
Review of special relativity
Curved spacetime of GR
Experimental tests of GR
GPS
Black holes
Gravitational waves
Introductory cosmology

Recommended Literature:
GRAVITY, by James Hartle
A FIRST COURSE IN GENERAL RELATIVITY, by Bernard Schutz
EXPLORING BLACK HOLES, by Taylor and Wheeler

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Lattice QCD (T)

Course No.: physics769

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	ST/WT

Requirements for Participation:

Preparation:
Quantum Mechanics 1+2, Quantum Field Theory 1

Form of Testing and Examination:
Written / oral examination

Length of Course:
1 semester

Aims of the Course:
To give an introduction to the quantum field theory on the lattice

Contents of the Course:
- Introduction: Quantum mechanics on the lattice
- Numerical algorithms
- Spin systems on the lattice: The Ising model
- Scalar field theory on the lattice: Discretization; Perturbation theory; Continuum limit
- Gauge fields: Link variables; Plaquette action; Wilson loop and confinement
- Fermions on the lattice: Fermion doubling; Different formulations for lattice fermions; Axial anomaly; Chiral fermions
- Use of Effective Field Theory methods: Extrapolation in the quark masses; Resonances in a finite volume

Recommended Literature:

J. Smit, Introduction to quantum fields on a lattice: A robust mate, Cambridge Lect. Notes Phys. (2002)

I. Montvay and G. Münster, Quantum Fields on a Lattice, Cambridge Monographs on Mathematical Physics, Cambridge University Press 1994

C. Gattringer and Ch. Lang, Quantum Chromodynamics on the Lattice: An Introductory Presentation Series: Lecture Notes in Physics, Vol. 788

H.J. Rothe, Lattice Gauge Theories: An Introduction, World Scientific, (2005)

Modules:

ECThPhysics **Elective Courses Theoretical Physics**
physics70c **Elective Advanced Lectures: Theoretical Physics**

Course: Advanced Quantum Field Theory (T)

Course No.: physics7501

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT

Requirements for Participation:

Preparation:
3-year theoretical physics course with extended interest in theoretical physics and mathematics

Form of Testing and Examination:
Requirements for the module examination (written examination): successful work with exercises

Length of Course:
1 semester

Aims of the Course:
Introduction to modern methods and developments in Theoretical Physics in regard to current research

Contents of the Course:
Selected Topics in Modern Theoretical Physics for example:
Anomalies
Solitons and Instantons
Quantum Fluids
Bosonization
Renormalization Group
Bethe Ansatz
Elementary Supersymmetry
Gauge Theories and Differential Forms
Applications of Group Theory

Recommended Literature:
M. Nakahara; Geometry, Topology and Physics (Institute of Physics Publishing, London 2nd Ed. 2003)
R. Rajaraman; Solitons and Instantons, An Introduction to Solitons and Instantons in Quantum Field Theory (North Holland Personal Library, Amsterdam 3rd reprint 2003)
A. M. Tsvelik; Quantum Field Theory in Condensed Matter Physics (Cambridge University Press 2nd Ed. 2003)
A. Zee; Quantum Field Theory in a Nutshell (Princeton University Press 2003)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Random Walks and Diffusion (T)

Course No.: physics7502

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	1+1	3	ST

Requirements for Participation:

Preparation:
Quantum mechanics and Thermodynamics

Form of Testing and Examination:
Requirements for the (written or oral) examination: Successful work within the exercises

Length of Course:
1 semester

Aims of the Course:
The aim of the course is to introduce the student to random processes and their application to diffusion phenomena

Contents of the Course:
Basics of probability theory, Master equation and Langevin equation, Law of large numbers and Central Limit Theorem, First passage problems, Large scale dynamics, Dynamical scaling.

Recommended Literature:
Will be announced in the first lecture

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Selected Topics in Modern Condensed Matter Theory (T)

Course No.: physics7503

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT

Requirements for Participation:

Preparation:
+ Introductory Condensed Matter Theory
+ Quantum Mechanics
+ Statistical Physics

Form of Testing and Examination:
oral or written examination

Length of Course:
1 semester

Aims of the Course:
Knowledge of topics of contemporary condensed matter research
Knowledge of theoretical methods of condensed matter physics

Contents of the Course:
Covers topics and methods of contemporary research, such as
+ Feynman diagram technique
+ Phase transitions and critical phenomena
+ Topological aspects of phenomena in condensed matter physic

Recommended Literature:
R. D. Mattuck, A Guide to Feynman Diagrams in the Many-Body Problem
N. Goldenfeld, Lectures on Phase Transitions and the Renormalization Group
B. A. Bernevig, Topological Insulators and Topological Superconductors

The course can be taken in parallel to physics617 Theoretical Condensed Matter Physics.

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Theory of Superconductivity and Superfluidity (T)

Course No.: physics7504

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	5	WT/ST

Requirements for Participation:

Preparation:
Quantum Mechanics, Thermodynamics and Statistics, Quantum Field Theory

Form of Testing and Examination:
Requirements for the (written or oral) examination: Successful participation in the exercises

Length of Course:
1 semester

Aims of the Course:
The goal of the course is to introduce students to the theory of superconductivity and superfluidity.

Contents of the Course:
Phenomenological theory of basic superconductivity, type I and type II superconductivity, vortices and their dynamics, Meissner-Ochsenfeld Effekt, microscopic theory of superconductivity: Gor'kov equation, BCS theory, Migdal theorem, strong coupling theory of superconductivity: Eliashberg equation, Andreev scattering, Josephson effect, Anderson theorem: impurity scattering, Collective excitations in superconductors and superfluids, Anderson (Higgs) mechanism for the mass generation. Superfluidity in 3He, superconductivity in heavy fermion compounds, high temperature superconductivity and open questions.

Recommended Literature:
Will be announced in the first lecture

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: High performance computing: Modern computer architectures and applications in the physical science (T)

Course No.: physics7505

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	2	3	WT/ST

Requirements for Participation:
Knowledge of a modern programming language like C/C++

Preparation:

Form of Testing and Examination:
oral examination

Length of Course:
1 semester

Aims of the Course:
Understanding principles of modern computer architectures and their usage and programming for scientific problems

Contents of the Course:
Computer architectures and system components (CPU, memory, network)
Software environment
Parallel architectures and parallel programming paradigms (MPI, OpenMP/threads)
High Performance Computing

Recommended Literature:
John L. Hennessy, David A. Patterson: Computer Architecture - A Quantitative Approach. Morgan Kaufmann Publishers, 2012
David A. Patterson, John L. Hennessy: Computer Organization and Design - The Hardware / Software Interface. Morgan Kaufmann Publishers, 2013
W.H. Press et al.: Numerical Recipes in C (Cambridge University Press)
Message Passing Interface Forum: MPI: A Message-Passing Interface Standard, Version 3.1
OpenMP Application Programming Interface, Version 4.5, November 2015

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Quark Distributions Functions (T)

Course No.: physics7506

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	2	3	WT

Requirements for Participation:

Preparation:
Quantum Field Theory (physics755 or equivalent)

Form of Testing and Examination:
oral examination

Length of Course:
1 semester

Aims of the Course:
By the end of the course, the student should be able to understand the formal parton model, renormalization of parton distributions, and current attempts to compute them on the lattice.

Contents of the Course:
Deep Inelastic Scattering; The Operator Product Expansion; Basics of the parton model; The formal parton model; Quark distributions and quasi-quark distributions; One loop corrections and renormalization; Lattice attempts to compute PDF

Recommended Literature:
Elliot Leader, Enrico Predazzi: An introduction to gauge theories and modern particle physics.
Cambridge Monographs on Particle physics, Nuclear Physics and Cosmology 1996.

John Collins: Foundations of Perturbative QCD.
Cambridge Monographs on Particle physics, Nuclear Physics and Cosmology 2011.

Anthony W. Thomas, Wolfram Weise: The Structure of the Nucleon. Wiley-VCH Verlag Berlin 2001.

R. K. Ellis, W. J. Stirling, B. R. Webber: QCD and Collider Physics.
Cambridge Monographs on Particle physics, Nuclear Physics and Cosmology 2003.

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Theory of Quantum Magnetism (T)

Course No.: physics7507

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

Requirements for Participation:

Preparation:
Quantum mechanics, Thermodynamics and Statistics, Quantum Field Theory

Form of Testing and Examination:
(1) form of examination: written or oral
(2) requirement for participation in examination: successful participation in exercises

Length of Course:
1 semester

Aims of the Course:
The goal of the course is to introduce students to advanced concepts in the theory of magnetism.

Contents of the Course:
Phenomenological theory of magnetism, spin exchange, ferro and anti-ferro magnetism, classically frustrated systems (Kagome lattice). Representations of spin algebras: Dyson-Maleev, Holstein, Primakov, Schwinger bosons, spin coherent states, spin path integral, non-linear sigma models, quantum phase transition, Bereshinski-Kosterlitz-Thouless transition, Haldane gap, frustrated magnets, valence bond states, spin liquids, quantum Heisenberg model (two dimensional, Kagome, pyrochlore lattice) Exactly solvable models (transfer matrix) Ising model. Exactly solvable models (Bethe Ansatz): XXZ model, Kondo model. Open problems in quantum magnetism.

Recommended Literature:
Will be announced in the first lecture

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Quantum Computing (T)

Course No.: physics7508

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT/ST

Requirements for Participation:

Preparation:
Theoretical courses at the Bachelor degree level

Form of Testing and Examination:
written / oral examination

Length of Course:
1 semester

Aims of the Course:
Understand the theory of quantum computing and apply it to existing hardware.

Contents of the Course:
- Quantum circuits
- Quantum algorithms
- Quantum computers
- Quantum noise and quantum operations
- Quantum error correction

Recommended Literature:
M. A. Nielsen and I. L. Chuang, Quantum Computation and Quantum Information, Cambridge

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Advanced Topics in Particle and Astroparticle Physics (T)

Course No.: physics7509

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT/ST

Requirements for Participation:

Preparation:
physics615 and physics711 strongly recommended, a course on General Relativity (e.g. physics754) would also be helpful.

Form of Testing and Examination:
Biweekly Homework Sheets + Final Written Exam

Length of Course:
1 semester

Aims of the Course:
To gain knowledge in Cosmological Perturbations, Axion physics, Dark Messenger physics/dark photons.

Contents of the Course:
1) Cosmological perturbations and effect on the CMB
2) Axions: Theory and Detection
3) Dark Photons: Theory and Detection

Recommended Literature:
1) Introduction to the Theory of the Early Universe, Vol. II (Cosmological perturbations and Inflationary Theory) by Gorbunov and Rubakov [World Scientic]on, Modern Cosmoless (Elsevier) 2
2) Modern Cosmology, Scott Dodelson (1st edition, 2003)
3) Various reviews on axions and dark photons.

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: QCD at colliders (T)

Course No.: physics7510

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	7	WT

Requirements for Participation:

Preparation:
Quantum Field Theory (physics755)

Form of Testing and Examination:
Requirements for the examination (written): successful work with the exercises.

Length of Course:
1 semester

Aims of the Course:
Understanding how to use perturbative quantum chromodynamics to perform calculations for collider experiments in modern high-energy physics.

Contents of the Course:
Quantum chromodynamics (QCD): quarks, gluons and the strong coupling constant
Tree-level scattering amplitudes: Feynman rules, modern methods for scattering amplitudes (BCFW recursion, scattering equations, ...)
Infrared divergences (collinear and soft singularities).
Loop corrections in QCD.
Cancellation of infrared divergences.
Parton model and parton distribution functions.
Modern methods for multi-loop computations.

Recommended Literature:
B. Webber, J. Stirling, R. K. Ellis; QCD and Collider Physics (Cambridge University Press 1996).
J. Campbell, J. Houston, F. Krauss; The Black Book of Quantum Chromodynamics: A Primer for the LHC Era (Oxford University Press 2017).
M. Peskin, D. V. Schroeder: An introduction to Quantum Field Theory (CRC Press 1995).
J. C. Plefka, J. M. Henn, Scattering Amplitudes in Gauge Theories (Springer 2014).
H. Elvang, Y.-T. Huang, Scattering Amplitudes in Gauge Theory and Gravity (Cambridge University Press 2015).

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Introduction to Integrability (T)

Course No.: physics7511

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	5	WT

Requirements for Participation:

Preparation:
Quantum Mechanics
(Quantum Field Theory/Statistical Physics useful but not necessary)

Form of Testing and Examination:
Requirements for the examination (written or oral): successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
Integrability is a property of special models or setups, which connects different physical and mathematical fields. The range of applications extends from classical mechanics to quantum field theory. The goal of this course is to gain an overview over the different facets and applications of integrability and to get to know interesting physical problems.

Contents of the Course:
Integrability and hidden symmetries of physical models, exactly solvable systems, classical and quantum integrability

Concepts & Methods:
Lax pairs, inverse scattering method, R-matrix, Yang-Baxter equation, factorized scattering, Bethe ansatz, nonlocal symmetries, quantum groups, Yangian symmetry

Models:
Elementary mechanical models, spin chains, field theories, AdS/CFT duality

Recommended Literature:
B. Sutherland. Beautiful Models: 70 Years of Exactly Solved Quantum Many-Body Problems
O. Babelon, D. Bernard, M. Talon. Introduction to Classical Integrable Systems.
P. Dorey. Exact S-matrices. http://arxiv.org/abs/hep-th/9810026
L. Faddeev. How algebraic Bethe ansatz works for integrable Model. http://arxiv.org/abs/hep-th/9605187.

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Introduction to Random Matrix Theory (T)

Course No.: physics7512

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+1	6	ST/WT

Requirements for Participation:

Preparation:
Complex Analysis, Theory I-IV is strongly recommended

Form of Testing and Examination:
Examination (written)

Length of Course:
1 semester

Aims of the Course:
Basic understanding of RMT and ist application

Contents of the Course:
Random matrix theory is a tool for understanding a wide variety of phenomena in physics and mathematics. It started with the idea of Wigner in the 1950's to describe the spectra of heavy nuclei with a random Hamiltonian. Surprisingly this idea worked and yielded some important physical information about this complicated system and lead to the notion of universality. RMT has wide range of applications in atomic physics, mesoscopic physics, QCD, quantum chaos, biophysics, number theory, finance and many others. The main topics of this course will be universality, symmetry classfication of RMTs, the logarithmic Coulomb gas,finite size effects, asymptotic analysis of the Riemann-Hilbert problem and applications to problems in quantum physics and statistical mechanics.

Recommended Literature:
Mehta M.L. Random matrices (3ed., Elsevier, 2004)
Potters M., Bouchaud J.P., A First Course in Random Matrix Theory (Cambridge University Press, 2020)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Introduction to Conformal Field Theory (T)

Course No.: physics7513

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	5	WT/ST

Requirements for Participation:

Preparation:
Quantum Field Theory

Form of Testing and Examination:
Requirements for the examination (written or oral): successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
Conformal symmetry represents a natural extension of Poincaré symmetry and plays an important role in many areas of theoretical physics. The aim of this course is to become acquainted with the basics of Conformal Field Theory (CFT) and to get an idea of applications in different contexts.

Contents of the Course:
CFT in two and higher dimensions, example CFTs, conformal bootstrap

Recommended Literature:
- Joshua D. Qualls, "Lectures on Conformal Field Theory", https://arxiv.org/abs/1511. 04074
- Marc Gillioz, "Conformal Field Theory for Particle Physicists", https://arxiv.org/abs/ 2207.09474
- Slava Rychkov, "EPFL Lectures on Conformal Field Theory in D >= 3 Dimensions", SpringerBriefs in Physics (2016), https://arxiv.org/abs/1601.05000
- Giuseppe Mussardo, "Statistical Field Theory", Oxford University Press (2020)
- P. Di Francesco, and P. Mathieu, and D. Senechal, "Conformal Field Theory", Graduate Texts in Contemporary Physics, Springer (1997)
- Ralph Blumenhagen, and Erik Plauschinn, "Introduction to Conformal Field Theory", Lect.Notes Phys. 779 (2009)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Introduction to Quantum Computing (T)

Course No.: physics7514

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+2	5	ST

Requirements for Participation:

Preparation:
Theoretical courses at the Bachelor degree level

Form of Testing and Examination:
Written / oral examination

Length of Course:
1 semester

Aims of the Course:
Understanding the theory and applications of quantum computing.

Contents of the Course:
- Quantum versus classical computing
- Quantum circuits and algorithms
- Quantum error correction and mitigation
- Applications in physics and chemistry

Recommended Literature:
M. A. Nielsen and I. L. Chuang, Quantum Computation and Quantum Information, Cambridge University Press.
A. Yu. Kitaev, A. H. Shen, and M. N. Vyalyi, Classical and Quantum Computation, American Mathematical Society.
J. Watrous, The Theory of Quantum Information, Cambridge University Press.

within the Transdisciplinary Research Area "Building Blocks of Matter and Fundamental Interactions"

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Introduction to the AdS/CFT Correspondence (T)

universitätbonn

Course No.: physics7515

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	5	WT/ST

Requirements for Participation:

Preparation:
Quantum Field Theory, General Relativity

Form of Testing and Examination:
Requirements for the examination (written or oral): successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
The correspondence between string theory on Anti-de-Sitter spacetime and conformal quantum field theory on its boundary represents one of the most active and inspiring research areas of theoretical physics in the last decades. The aim of this course is to review the basic concepts to understand this duality between two a priory very different theories and to study some of ist implications and applications.

Contents of the Course:
basics of conformal field theory, supersymmetry and string theory, N=4 Super Yang-Mills theory, statement and selected applications of the AdS/CFT correspondence, integrable structures in planar AdS/CFT

Recommended Literature:

* Horatio Nastase, Lecture Notes "Introduction to AdS/CFT", https://arxiv.org/abs/0712.0689 or the book "Introduction to the AdS/CFT Correspondence", Cambridge University Press
* Makoto Natsuume, "AdS/CFT Duality User Guide", Lect.Notes Phys. 903 (2015) pp.1-294, https://arxiv.org/abs/1409.3575
* Joao Penedones, "TASI lectures on AdS/CFT", https://arxiv.org/abs/1608.04948
* Niklas Beisert et al, "Review of AdS/CFT Integrability: An Overview", Lett.Math.Phys. 99 (2012), https://arxiv.org/abs/1012.3982
* Diego Bombardelliet al, "An integrability primer for the gauge-gravity correspondence", J.Phys.A 49 (2016) 32, https://arxiv.org/abs/1606.02945

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Machine Learning for Quantum Scientists (T)

Course No.: physics7516

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+2	5	WT/ST

Requirements for Participation:

Preparation:
Theoretical courses at the Bachelor degree level

Form of Testing and Examination:
Written / oral examination

Length of Course:
1 semester

Aims of the Course:
Understanding the basics of machine learning and applications in quantum sciences

Contents of the Course:
- Basic structure, training, and analysis of artificial neural networks
- Standard architectures for machine learning, including convolutional neural networks, Boltzmann machines, and deep generative models
- Applications of machine learning in theoretical physics and chemistry

Recommended Literature:
C. M. Bishop, "Pattern Recognition and Machine Learning", Springer.
I. Goodfellow, Y. Bengio, A. Courville, "Deep Learning", MIT Press.
A. Dawid, et al., "Modern Applications of Machine Learning in Quantum Sciences", Cambridge University Press

within the Transdisciplinary Research Area "Building Blocks of Matter and Fundamental Interactions"

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Quantum chaos: tools and applications (T)

Course No.: physics7517

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	5	WT

Requirements for Participation:

Preparation:
Classical mechanics, Quantum mechanics, Statistical mechanics (recommended). Special interest in quantum dynamics and nonlinear systems.

Form of Testing and Examination:
Requirements for the examination (written or oral): successful work with the exercises

Length of Course:
1 semester

Aims of the Course:
Knowledge on the theory of chaos, tools to analyze it in quantum systems with examples, as well as its manifestation in many-body systems that can be realized on the experimental platforms.

Contents of the Course:
1. Introduction and classification of dynamical systems
- From macroscopic, mesoscopic to microscopic systems, Different dynamics: simple to complex.

2. Chaos in classical systems
- Discrete dynamical system: One dimensional maps
- Hamiltonian systems: Phase space and Hamilton’s equation
- Poincare map
- Stroboscopic Maps of Periodically Driven Systems: Kicked rotor
- KAM theorem
- Lyapunov exponent, Kolmogorov-Sinai entropy

3. Aspects of quantum chaos
- Quantum classical correspondence
- EBK quantization
- Gutzwiller’s Trace formula
- Phase space densities and Wigner function
- Anderson and dynamical localization

4. Level statistics: Application of Random Matrix Theory
- Gaussian Ensembles of Hermitian Matrices
- Level Spacing Distributions
- Unfolding Spectra
- Eigenvector statistics
- Dyson’s Brownian-Motion Model

5. Quantum chaos and ergodicity in many-body systems
- Quantum butterfly effect
- Out-of-time-ordered correlator (OTOC)
- Ergodicity and quantum scar
- Example from collective quantum systems: Dicke model, Josephson junction

Recommended Literature:

- F. Haake, Quantum Signatures of Chaos, Springer Science and Business Media (Springer, 2013).
- S. Wimberger, Nonlinear Dynamics and Quantum Chaos: An Introduction (Springer, 2014).
- H.-J. Stöckmann, Quantum Chaos, An Introduction (Cambridge University Press, 1999).

Modules:

physics70a **Elective Advanced Lectures: Experimental Physics**
physics70b **Elective Advanced Lectures: Applied Physics**
physics70c **Elective Advanced Lectures: Theoretical Physics**

Course: universitätbonn Research Project

Course No.: physics799

Category	Type	Language	Teaching hours	CP	Semester
Elective	Research Project	English		4	WT/ST

Requirements for Participation:
Students are asked to contact one of the BCGS lecturers prior to the start of their research project. Lecturers provide help if needed to find a suitable research group and topic. Not all groups may have projects available at all times, thus participation may be limited.

Preparation:
A specialization lecture from the research field in question or equivalent preparation.

Form of Testing and Examination:
A written report or, alternatively, a presentation in a meeting of the research group.

Length of Course:
4-6 weeks

Aims of the Course:
Students conduct their own small research project as a part-time member of one of the research groups in Bonn. The students learn methods of scientific research and apply them to their project.

Contents of the Course:
One of the following possible items:
- setting up a small experiment,
- analyzing data from an existing experiment,
- simulating experimental situations,
- numerical or analytical calculations in a theory group.

Recommended Literature:
provided by the supervisor within the research group.

registration by written application to the examination office (see homepage)