Module: Elective Advanced Lectures: Theoretical Physics

Module Elements:

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Course Title</th>
<th>Number</th>
<th>CP</th>
<th>Type</th>
<th>Workload</th>
<th>Sem.</th>
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<tbody>
<tr>
<td>1.</td>
<td>Selected courses from catalogue type &quot;T&quot; (Theoretical)</td>
<td>see catalogue</td>
<td>5-7</td>
<td>see catalogue</td>
<td>150-210 hrs</td>
<td>WT/ST</td>
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<td>2.</td>
<td>Also possible classes from M.Sc. in Astrophysics</td>
<td></td>
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</tbody>
</table>

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:

Note: The student must achieve at least 18 CP out of all 4 Elective Advanced Modules
Degree: M.Sc. in Physics (PO von 2014)

Modules:

- physics70a Elective Advanced Lectures: Experimental Physics
- physics70c Elective Advanced Lectures: Theoretical Physics

Course: Ultracold Atomic Gases (E/T)

Course No.: physics742

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
<th>Language</th>
<th>Teaching hours</th>
<th>CP</th>
<th>Semester</th>
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<td>Elective</td>
<td>Lecture with exercises</td>
<td>English</td>
<td>3+1</td>
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</table>

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.


Recommended Literature:
C. J. Pethick and H. Smith, Bose-Einstein Condensation in Dilute Gases (Cambridge University Press)
Degree: M.Sc. in Physics (PO von 2014)

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

Course: Group Theory (T)

Course No.: physics751

<table>
<thead>
<tr>
<th>Category</th>
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<th>Teaching hours</th>
<th>CP</th>
<th>Semester</th>
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<td>Lecture with exercises</td>
<td>English</td>
<td>3+2</td>
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</table>

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: Superstring Theory (T)

Course No.: physics752

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
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<th>CP</th>
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<td>English</td>
<td>3+2</td>
<td>7</td>
<td>WT</td>
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</tbody>
</table>

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)
- 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

<table>
<thead>
<tr>
<th>Category</th>
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<td>Elective</td>
<td>Lecture with exercises</td>
<td>English</td>
<td>3+2</td>
<td>7</td>
<td>ST</td>
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</table>

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;
- baryogenesis,
- Dark Matter,
- nucleosynthesis
- the cosmology and astrophysics of neutrinos

Recommended Literature:
- E. Kolb, M. Turner; The Early Universe (Addison Wesley 1990)
**Degree:** M.Sc. in Physics (PO von 2014)

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

**Course:**

**General Relativity and Cosmology (T)**

**Course No.:** physics754

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**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
- Curvilinear 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)
- 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
Degree: M.Sc. in Physics (PO von 2014)

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

Course: Quantum Field Theory (T)

Course No.: physics755

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<td>ST</td>
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</table>

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

<table>
<thead>
<tr>
<th>Category</th>
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<th>Semester</th>
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<td>3+2</td>
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</table>

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:
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

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
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<th>Teaching hours</th>
<th>CP</th>
<th>Semester</th>
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<td>English</td>
<td>3+2</td>
<td>7</td>
<td>WT/ST</td>
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</table>

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)
A.V. Manohar, M.B. Wise; Heavy Quark Physics (Cambridge University Press 2007)
D.B. Kaplan, Effective Field Theories (arXiv:nucl-th/9506035)
Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Quantum Chromodynamics (T)

Course No.: physics758

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
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<th>CP</th>
<th>Semester</th>
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<td>English</td>
<td>3+2</td>
<td>7</td>
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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)
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.: physics759

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
<th>Language</th>
<th>Teaching hours</th>
<th>CP</th>
<th>Semester</th>
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<td>Elective</td>
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<td>English</td>
<td>2+1</td>
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<td>WT/ST</td>
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</table>

Requirements for Participation:
Quantum mechanics I (physik421)

Preparation:
Quantum mechanics II (physics606), Thermodynamics and statistical physics (physik521)
Can be heard in parallel to physics617: “Theoretical Condensed Matter Physics”

Form of Testing and Examination:
Requirements for the examination (written or oral): attendance of and 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 diagram

Contents of the Course:
Fock space and occupation number representation for bosons and fermions
Green's functions: analytical properties and their relation to observable quantities
Elementary linear response theory
Equations of motion
Perturbation theory in thermodynamic equilibrium: Feynman diagrams, Matsubara technique
Perturbation theory away from equilibrium: Keldysh technique
Infinite resummations of perturbation expansions
Exemplary application to model system

Recommended Literature:
W. Nolting, Grundkurs Theoretische Physik 7: Vielteilchen-Theorie (Springer, Heidelberg 2009)
A. A. Abrikosov, L. P. Gorkov, I. E. Dzyaloshinskii, Methods of Quantum Field Theory in Statistical Physics (Dover, New York 1975 and later editions)
Degree: M.Sc. in Physics (PO von 2014)

Modules:

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

Course: Computational Physics (T)

Course No.: physics760

<table>
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<tr>
<th>Category</th>
<th>Type</th>
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<th>Teaching hours</th>
<th>CP</th>
<th>Semester</th>
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<tr>
<td>Elective</td>
<td>Lecture with exercises and project work</td>
<td>English</td>
<td>2+2+1</td>
<td>7</td>
<td>WT/ST</td>
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</table>

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:
  http://library.lanl.gov/numerical/index.html
Tao Pang: An Introduction to Computational Physics (Cambridge University Press)
Binder, Kurt and Heermann, Dieter W.: Monte Carlo Simulation in Statistical Physics (Springer)
Fehske, H.; Schneider, R.; Weisse, A.: Computational Many-Particle Physics (Springer)

June 2010
Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Supersymmetry (T)

Course No.: physics761

<table>
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<tr>
<th>Category</th>
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<td>Elective</td>
<td>Lecture with exercises</td>
<td>English</td>
<td>3+1</td>
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</table>

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.

Weak scale supersymmetry: From superfields to scattering events.
Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Transport in mesoscopic systems (T)

Course No.: physics762

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
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<th>CP</th>
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<td>Elective</td>
<td>Lecture with exercises</td>
<td>English</td>
<td>2+1</td>
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<td>WT/ST</td>
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</table>

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:
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

October 2010
Degree: M.Sc. in Physics (PO von 2014)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Advanced Topics in String Theory (T)

Course No.: physics763

<table>
<thead>
<tr>
<th>Category</th>
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<td>Elective</td>
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<td>English</td>
<td>3+2</td>
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</table>

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:
M. Green, J. Schwarz, E. Witten: Superstring Theory I & II (Cambridge University Press 1988)
J. Polchinski: String Theory I & II (Cambridge University Press 2005)
Degree: M.Sc. in Physics (PO von 2014)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

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

Course No.: physics764

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
<th>Language</th>
<th>Teaching hours</th>
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<tr>
<td>Elective</td>
<td>Lecture with exercises</td>
<td>English</td>
<td>3+2</td>
<td></td>
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</table>

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
Degree: M.Sc. in Physics (PO von 2014)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Advanced Topics in Quantum Field Theory (T)

Course No.: physics765

<table>
<thead>
<tr>
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<tr>
<td>Elective</td>
<td>Lecture with exercises</td>
<td>English</td>
<td>3+2</td>
<td>7</td>
<td>ST</td>
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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

<table>
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<tr>
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<td>7</td>
<td>WT</td>
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</table>

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)
Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Computational Methods in Condensed Matter Theory (T)

Course No.: physics767

<table>
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<tr>
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<td>3+2</td>
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</table>

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
**Degree:** M.Sc. in Physics (PO von 2014)

**Module:** Elective Advanced Lectures: Theoretical Physics

**Module No.:** physics70c

**Course:** General Relativity for Experimentalists (T)

**Course No.:** physics768

<table>
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**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
Degree: M.Sc. in Physics (PO von 2014)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Course No.: physics769

Lattice QCD (T)

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</table>

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:
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
Degree: M.Sc. in Physics (PO von 2014)

Modules:

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<td>Elective Courses Theoretical Physics</td>
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<tr>
<td>physics70c</td>
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<td>Elective Advanced Lectures: Theoretical Physics</td>
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Course: Advanced Quantum Field Theory (T)

Course No.: physics7501

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</table>

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:
R. Rajaraman; Solitons and Instantons, An Introduction to Solitons and Instantons in Quantum Field Theory (North Holland Personal Library, Amsterdam 3rd reprint 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

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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

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</table>

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 physics

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.
Degree: M.Sc. in Physics (PO von 2014)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Theory of Superconductivity and Superfluidity (T)

Course No.: physics7504

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<tr>
<th>Category</th>
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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
Degree: M.Sc. in Physics (PO von 2014)

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

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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:
OpenMP Application Programming Interface, Version 4.5, November 2015
Degree: M.Sc. in Physics (PO von 2014)

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Quark Distributions Functions (T)

Course No.: physics7506

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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:


Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Theory of Quantum Magnetism (T)

Course No.: physics7507

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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:

Recommended Literature:
Will be announced in the first lecture
Degree: M.Sc. in Physics (PO von 2014)

**Module:** Elective Advanced Lectures: Theoretical Physics

**Module No.:** physics70c

**Course:** Quantum Computing (T)

**Course No.:** physics7508

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**Requirements for Participation:**
Quantum Mechanics I

**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
**Degree:** M.Sc. in Physics (PO von 2014)

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

**Course:** Research Project

**Course No.:** physics799

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</table>

**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.