Module-Handbook

Master in Physics

PO von 2014

SS 2025

March 2025

We don’t offer each of these modules regularly.

For any update please see:

https://www.physik-astro.uni-bonn.de/de/studium/

lehrveranstaltungen/termine-und-lehrveranstaltungen

Master of Physics

Rheinische Friedrich-Wilhelms-Universität Bonn

(valid from WS 2014/2015)

Course Phase

Compulsory

1. Sem. (Oct, Nov, Dec, Jan, Feb, Mar) – 2. Sem. (Apr, May, June, July, Aug, Sep)

physics601: Advanced Laboratory Course	7 cp

Elective

Theoretical Physics (**physics606** or - if done previously - 1 module out of physics751, physics754, physics755, physics760, physics7501)	7 cp
Specialization (at least 24 cp out of physics61a, -61b, -61c and/or physics62a, -62b, -62c)	24 cp
Elective Advanced Lectures (at least 18 cp out of physics70a, -70b, -70c, -70d)	18 cp
Seminar (1 seminar out of physics65a, -65b, -65c)	4 cp

Research Phase

3. Sem. (Oct, Nov, Dec, Jan, Feb, Mar)

physics910: Scientific Exploration of the Master thesis topic	15 cp
physics920: Methods and Project Planning	15 cp

4. Sem. (Apr, May, June, July, Aug, Sep)

physics930: Master Thesis	30 cp

Table of Contents: M.Sc. in Physics (PO von 2014)

Module No.:	physics601	
Credit Points (CP):	7	
Category:	Required	
Semester:	1.	

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Advanced Laboratory Course

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Advanced Laboratory Course	physics601	7	Laboratory	210 hrs	WT/ST

Requirements for Participation:

Form of Examination:
written report for every laboratory

Content:
Every student has to complete this Laboratory Course. The course consists of advanced experiments introducing into important subfields of contemporary experimental physics and astrophysics. The lab-course is accompanied by a seminar.

Aims/Skills:
The students shall gain insight in the conceptual and complex properties of relevant contemporary experiments. The students gain experience in setting up an experiment, data logging and data analysis. They experience the intricacies of forefront experimental research

Course achievement/Criteria for awarding cp's:
Before carrying out an experiment, the students shall demonstrate to have acquired the necessary preparatory knowledge. Experiments are selected from the catalogue of laboratory set-ups offered. Cumulative lab-units of >= 9 are required.
Requirements for the examination (written report for every laboratory): successful completion of the experiment and initial oral questioning plus seminar talk

Length of Module: 1 semester

Maximum Number of Participants: ca. 100

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

Module: Advanced Laboratory Course

Module No.: physics601

Course: Advanced Laboratory Course

Course No.: physics601

Category	Type	Language	Teaching hours	CP	Semester
Required	Laboratory	English	3+2	7	WT/ST

Requirements for Participation:
Lab course physik661 "Praktikum Kerne und Teilchen" or successful completion of the experiment "Nuclear electronics and lifetime measurement" of physik661.

Preparation:
An appropriate knowledge of the physics background and the experimental environment of the laboratories is required. Recommended lectures are specified in the catalogue of laboratories.

Form of Testing and Examination:
Experiments are selected from the catalogue of laboratory setups offered. Five experiments are required. One of the experiments 1-3 is compulsory for physics students. Two of the experiments 14-17 are compulsory for astrophysics students. Requirements for the module examination (written report for every laboratory): successful completion of the experiment and initial oral questioning

Length of Course:
1 semester

Aims of the Course:
The student shall gain insight in the intricate workings of physics in relevant advanced experiments. The student gains experience in the setting up of a proper experimental environment and experiences the intricacies of forefront experimental research and presenting his/her results.

Contents of the Course:
Advanced experiments are carried out. Experimenting time ~8 to 16 hrs, preparation time and report writing each ~15 hrs. The experiments are chosen among those being offered and after consultation with the head of the course.
In the accompanying seminar the students report about one experiment. This experiment will be selected after consultation with the head of the course.

Recommended Literature:
Hand outs and literature will be distributed with the registration for an experiment

Catalogue of laboratories: (subject to change, for an up-to-date catalogue see https://www.physik-astro.uni-bonn.de/praktika/en/modules/physics601)

1. Analysis of decays of heavy vector boson Z0
2. ATLAS
3. Investigation of particle-antiparticle oscillations at BELLE-II
4. Radiofrequency cavities for particle acceleration
5. Lab course accelerator Bonn (LAB)
6. Properties of elementary particles
7. STYX
8. Positron lifetime in metals and insulators
9. Nuclear y-y angular correlations
10. Optical frequency doubling
11. Laser spectroscopy
12. Magneto-optic trap

13. Laser Gyroscope
14. Optical astronomy (Recommended: astro800 Introduction to Astrophysics or an equivalent basic knowledge in astrophysics)
15. Setting up a Radio-astronomical receiver / Setting up a Radio Interferometer (Recommended: lecture astro123 "Einführung in die Radioastronomie" or lecture astro841 Radio Astronomy: tools, application, impacts)
16. Photometry of star clusters
17. Radio astronomical observing course (Recommended: lecture astro123 "Einführung in die Radioastronomie" or lecture astro841 Radio Astronomy: tools, application, impacts

Module No.: ECThPhysics
Credit Points (CP): 7
Category: Elective
Semester: 1.

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Elective Courses Theoretical Physics

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Advanced Quantum Theory	physics606	7	Lect. + ex.	210 hrs	WT
2.	Group Theory (T)	physics751	7	Lect. + ex.	210 hrs	WT
3.	General Relativity and Cosmology (T)	physics754	7	Lect. + ex.	210 hrs	ST
4.	Quantum Field Theory (T)	physics755	7	Lect. + ex.	210 hrs	ST
5.	Computational Physics (T)	physics760	7	Lect. + ex. + proj.	210 hrs	WT/ST
6.	Advanced Quantum Field Theory (T)	physics7501	7	Lect. + ex.	210 hrs	WT

Requirements for Participation:
for physics606: none
for all other modules: physics606

Form of Examination:
written examination

Content:
see with the course

Aims/Skills:
see with the course

Course achievement/Criteria for awarding cp's:
successfull work with the exercises

Length of Module: 1 semester

Maximum Number of Participants: ca. 100

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

at least 7 cp out of this area must be achieved

Module: Elective Courses Theoretical Physics

Module No.: ECThPhysics

Course: Advanced Quantum Theory

Course No.: physics606

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

Requirements for Participation:

Preparation:
Theoretical courses at the Bachelor degree level

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:
Ability to solve problems in relativistic quantum mechanics, scattering theory and many-particle theory

Contents of the Course:
Born approximation, partial waves, resonances
advanced scattering theory: S-matrix, Lippman-Schwinger equation
relativistic wave equations: Klein-Gordon equation, Dirac equation
representations of the Lorentz group
many body theory
second quantization
basics of quantum field theory
path integral formalism
Greens functions, propagator theory

Recommended Literature:
L. D. Landau, E.M. Lifschitz; Course of Theoretical Physics Vol.3 Quantum Mechanics (Butterworth-Heinemann 1997)
J. J. Sakurai, Modern Quantum Mechanics (Addison-Wesley 1995)
F. Schwabl, Advanced Quantum Mechanics. (Springer, Heidelberg 3rd Ed. 2005)

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)

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: 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)

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)

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 No.: physics61a
Credit Points (CP): 6
Category: Elective
Semester: 1.

Fachgruppe Physik und Astronomie Universität Bonn

Module: Specialization: Experimental Physics

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
Particle Physics						
1.	Particle Physics	physics611	6	Lect. + ex.	180 hrs	WT
2.	Accelerator Physics	physics612	6	Lect. + ex.	180 hrs	WT
3.	Physics of Particle Detectors	physics618	6	Lect. + ex.	180 hrs	WT
Condensed Matter and Photonics						
1.	Condensed Matter Physics	physics613	6	Lect. + ex.	180 hrs	WT
2.	Advanced Atomic, Molecular, and Optical Physics	physics620	6	Lect. + ex.	180 hrs	WT
3.	Quantum Optics	physics631	6	Lect. + ex.	180 hrs	WT
4.	Condensed Matter Physics I	CondMatter I	6	Lect. + ex.	180 hrs	WT
5.	Molecular Physics I	MolPhys I	6	Lect. + ex.	180 hrs	WT

Requirements for Participation:

Form of Examination:
see with the course

Content:
Fundamentals in experimental physics in Bonn or Cologne

Aims/Skills:
The students will get acquainted with modern research topics

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

Length of Module: 1 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 24 CP out of all 6 Specialization Modules

Module: Specialization: Experimental Physics

Module No.: physics61a

Course: Particle Physics

Course No.: physics611

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

Requirements for Participation:

Preparation:
Introductory particle physics and quantum mechanics courses

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 of the fundamentals of particle physics: properties of quarks and leptons and their interactions (electromagnetic, weak, strong), experiments that have led to this understanding, the Standard Model of particle physics and measurements that test this model, the structure of hadrons

Contents of the Course:
Basics: leptons and quarks, antiparticles, hadrons, forces / interactions, Feynman graphs, relativistic kinematics, two-body decay, Mandelstam variables, cross-section, lifetime
Symmetries and Conservation Laws. Positronium, Quarkonium. Accelerators and Detectors
Electromagnetic interactions: (g-2) experiments, lepton-nucleon scattering
Strong interactions: colour, gauge principle, experimental tests of QCD. Electroweak interactions and the Standard Model of particle physics: spontaneous symmetry breaking, Higgs mechanism, experimental tests of the Standard Model. Neutrino physics, neutrino oscillations; CP violation

Recommended Literature:
F Halzen, A. Martin; Quarks and Leptons (J. Wiley, Weinheim 1. Aufl. 1984)
C. Berger; Elementarteilchenphysik (Springer, Heidelberg 2. überarb. Aufl. 2006)
Perkins; Introduction to High Energy Physics (Cambridge University Press 4. Aufl. 2000)
D. Griffith; Introduction to Elementary Particle Physics (J. Wiley, Weinheim 1. Aufl. 1987)
A. Seiden; Particle Physics : A Comprehensive Introduction (2005)
Martin & Shaw; Particle Physics, Wiley (2nd edition, 1997)

Module: Specialization: Experimental Physics

Module No.: physics61a

Course: Accelerator Physics

Course No.: physics612

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

Requirements for Participation:

Preparation:

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 of the functional principle of different types of particle accelerators
Layout and design of simple magneto-optic systems
Basic knowledge of radio frequency engineering and technology
Knowledge of linear beam dynamics in particle accelerators

Contents of the Course:
Elementary overview of different types of particle accelerators: electrostatic and induction accelerators, RFQ, Alvarez, LINAC, Cyclotron, Synchrotron, Microtron
Subsystems of particle accelerators: particle sources, RF systems, magnets, vacuum systems
Linear beam optics: equations of motion, matrix formalism, particle beams and phase space
Circular accelerators: periodic focusing systems, transverse beam dynamics, longitudinal beam dynamics
Guided tours through the ELSA accelerator of the Physics Institute and excursions to other particle accelerators (COSY, MAMI, HERA, ...) complementing the lecture

Recommended Literature:
F. Hinterberger; Physik der Teilchenbeschleuniger und Ionenoptik (Springer Heidelberg 1997)
H. Wiedemann; Particle Accelerator Physics (Springer, Heidelberg 2. Aufl. 1999)
K. Wille; Physik der Teilchenbeschleuniger und Synchrotronstrahlungsquellen (Teubner, Wiesbaden 2. Aufl. 1996)
D. A. Edwards, M.J. Syphers; An Introduction to the Physics of High Energy Accelerators, Wiley & Sons 1993)
Script of the Lecture "Particle Accelerators"
http://www-elsa.physik.uni-bonn.de/~hillert/Beschleunigerphysik/

Module: Specialization: Experimental Physics

Module No.: physics61a

Course: Physics of Particle Detectors

Course No.: physics618

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

Requirements for Participation:

Preparation:
Useful: physik510

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 the basics of the physics of particle detectors, their operation and readout

Contents of the Course:
Physics of detectors and detection mechanisms, interactions of charged particles and photons with matter, ionization detectors, drift and diffusion, gas filled wire chambers, proportional and drift chambers, semiconductor detectors, microstrip detectors, pixel detectors, radiation damage, cerenkov detectors, transition radiation detectors, scintillation detectors (anorganic crystals and plastic scintillators), electromagnetic calorimeters, hadron calorimeters, readout techniques, VLSI readout and noise

Recommended Literature:
Wermes: Skriptum and web-based Teaching Module
K. Kleinknecht; Detectors for Particle Radiation (Cambridge University Press 2nd edition 1998)
W.R. Leo; Techniques for Nuclear and Particle Detection (Springer, Heidelberg 2nd ed. 1994)
H. Spieler, Semiconductor detector system (Oxford University Press 2005)
L. Rossi, P. Fischer, T. Rohe, N. Wermes, Pixel Detectors: From Fundamentals to Applications (Springer 2006)

Module: Specialization: Experimental Physics

Module No.: physics61a

Course: Condensed Matter Physics

Course No.: physics613

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

Requirements for Participation:

Preparation:

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 of the concepts of condensed matter physics

Contents of the Course:
Crystallographic structures: Bravais lattices, Millers indices, crystallographic defects, structural analysis;
Chemical bonds: van der Waals bond, covalent bond, hybridisation, ionic bond, metallic bond, Hydrogen bridge bond;
Lattice vibrations: acoustic and optical phonons, specific heat, phonon-phonon interaction;
Free electrons in the solid state: free electron gas, Drude model, Fermi distribution, specific heat of the electrons;
Band structure: metals, semiconductors, insulators, effective masses, mobility of charge carrier, pn-transition, basic principles of diodes, bipolar and unipolar transistors;
Superconductivity: basic phenomena, Cooper pairs, BSC-theory and its consequences;
Magnetic properties: diamagnetism, Langevin-theory of paramagnetism, Pauli-paramagnetism, spontaneous magnetic order, molecular field, Heisenberg-exchange;
Nuclear solid state physics: Hyperfine interaction, Mössbauer spectroscopy, perturbed angular correlation, positron annihilation, typical applications.

Recommended Literature:
N. W. Ashcroft , N. D. Mermin , Solid State Physics (Brooks Cole 1976) ISBN-13: 978-0030839931
N. W. Ashcroft , N. D. Mermin, Festkörphysik (Oldenbourg 2001) ISBN-13: 978-3486248340
H. Ibach, H. Lüth, Solid-State Physics (Springer 2003) ISBN-13: 978-3540438700
H. Ibach, H. Lüth, Festkörperphysik (Springer 2002) ISBN-13: 978-3540427384
C. Kittel, Einführung in die Festkörperphysik (Oldenbourg 2006) ISBN-13: 978-3-486-57773-5
W. Demtröder, Experimentalphysik, Bd. 3. Atome, Moleküle und Festkörper (Springer 2005) ISBN-13: 978-3540214731
K. Kopitzki, P. Herzog Einführung in die Festkörperphysik (Vieweg+Teubner 2007) ISBN-13: 978-3835101449
L. Bergmann, C. Schaefer, R. Kassing, Lehrbuch der Experimentalphysik 6.: Festkörper (Gruyter 2005) ISBN-13: 978-3110174854
W. Buckel, R. Kleiner, Supraleitung (Wiley-VCH 2004) ISBN-13: 978-3527403486

Module: Specialization: Experimental Physics

Module No.: physics61a

Course: Advanced Atomic, Molecular, and Optical Physics

Course No.: physics620

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

Requirements for Participation:

Preparation:
Fundamentals of Quantum Mechanics, Atomic Physics

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

Length of Course:
1 semester

Aims of the Course:
The aim of the course is to give the students a deeper insight to the field of atomic, molecular and optical (AMO) physics. Building on prior knowledge from the Bachelor courses it will cover advanced topics of atomic and molecular physics, as well as the interaction of light and matter.

Contents of the Course:
Atomic physics: Atoms in external fields; QED corrections: Lamb-Shift; Interaction of light and matter: Lorentz oscillator, selection rules; magnetic resonance; Coherent control

Molecular physics: Hydrogen Molecule; Vibrations and rotations of molecules; Hybridization of molecular orbitals; Feshbach Resonances; Photoassociation; Cold Molecules

Bose Condensation; Matterwave Optics

Recommended Literature:
C. J. Foot, Atomic Physics, Oxford University Press 2005
H. Haken, The physics of atoms and quanta, Springer 1996
S. Svanberg, Atomic and molecular spectroscopy basic aspects and practical applications, Springer 2001
W. Demtröder, Molecular Physics, Wiley VCH 2005
T. Buyana, Molecular physics, World Scientific 1997
W. Demtröder, Atoms, Molecules and Photons, Springer 2010
P, Meystre, Atom Optics, Springer 2010

Module: Specialization: Experimental Physics

Module No.: physics61a

Course: Quantum Optics

Course No.: physics631

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

Requirements for Participation:

Preparation:

Form of Testing and Examination:
Examination written or oral (announced at the beginning of the module).
Prerequisite for participation in the exam: successful work within the exercises.

Length of Course:
1 semester

Aims of the Course:
Make the students understand quantum optics and enable them to practically apply their knowledge in research and development.

Contents of the Course:
Quantization of the electromagnetic field, single-mode quantum optics
Representations of the light field; Quasi-probabilities
Coherence, correlation functions;
Nonclassical light
Interaction of quantized radiation and atoms;
Introduction to quantum information

Recommended Literature:
R. Loudon; The quantum theory of light (Oxford University Press 2000)
G. J. Milburn, D. F. Walls; Quantum Optics (Springer 1994)
C. Gerry, P. Knight; Introductory quantum optics (Cambridge University Press 2004)
D. Meschede; Optics, Light and Lasers (Wiley-VCH, 3rd ed. 2017)
M. O. Scully, M. S. Zubairy; Quantum Optics (Cambridge 1997)
P. Meystre, M. Sargent; Elements of Quantum Optics (Springer 1999)

Module: Specialization: Experimental Physics

Module No.: physics61a

Course: Condensed Matter Physics I

Course No.:

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

Requirements for Participation:

Preparation:
Basic knowledge in condensed matter physics and quantum mechanics

Form of Testing and Examination:
Oral or written examination

Length of Course:
2 semesters

Aims of the Course:
Comprehensive introduction to the basic principles of solid state physics and to some experimental methods. Examples of current research will be discussed.

Contents of the Course:
The entire course (Condensed Matter I & II, given in 2 semesters) covers the following topics:
Crystal structure and binding
Reciprocal space
Lattice dynamics and thermal properties
Electronic structure (free-electron gas, Fermi surface, band structure)
Semiconductors and metals
Transport properties
Dielectric function and screening
Superconductivity
Magnetism

Recommended Literature:
Skriptum (available during the course)
Ashcroft/Mermin: Solid State Physics
Kittel: Introduction to Solid State Physics
Ibach/Lüth: Festkörperphysik

Module: Specialization: Experimental Physics

Module No.: physics61a

Course: Molecular Physics I

Course No.:

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

Requirements for Participation:

Preparation:
Atomic Physics, Molecular Physics and Quantum Mechanics at the level of the bachelor courses in physics

Form of Testing and Examination:
Oral Examination

Length of Course:
1 semester

Aims of the Course:
In the first part of the core courses the students learn the main concepts of molecular physics: separation of electronic, vibrational and rotational motion. Simple molecular spectra can be analyzed on the basis of the problem class. Fundamental group theory is used to predict vibrational and rotational spectra of more complex molecules.

This module prepares for topics of current research in molecular physics and provides the basis for the preparation of the master thesis.

Contents of the Course:
- Basics of molecular spectroscopy, phenomenology, diatomic molecules
- Born-Oppenheimer Approximation, separation of rotation and vibration
- Molecular Dipole moment and rotational transitions
- Rotational spectra and the rigid rotor approach
- Selection rules, parallel and perpendicular type spectra
- Nuclear spin statistics
- Hyperfine structure of molecular lines

Recommended Literature:
Bernath, "Spectra of Atoms and Molecules", Oxford University Press)
Townes Schawlow, "Microwave Spectroscopy" (Dover Publications)
Gordy & Cook, Microwave Spectra" (Wiley)
Engelke, "Aufbau der Moleküle" (Teubner)
P. R. Bunker and Per Jensen: "Molecular Symmetry and Spectroscopy, 2nd Edition", (NRC Research Press, Ottawa)

Module No.: physics62a
Credit Points (CP): 6
Category: Elective
Semester: 2.

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Specialization: Advanced Experimental Physics

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
Particle Physics						
1.	Physics of Hadrons	physics632	6	Lect. + ex.	180 hrs	ST
2.	High Energy Collider Physics	physics633	6	Lect. + ex.	180 hrs	ST
3.	Advanced Topics in High Energy Particle Physics	physics639	6	Lect. + ex.	180 hrs	ST
Condensed Matter and Photonics						
1.	Magnetism/Superconductivity	physics634	6	Lect. + ex.	180 hrs	ST
2.	Photonics	physics641	6	Lect. + ex.	180 hrs	ST
3.	Quantum Technology	physics642	6	Lect. + ex.	180 hrs	ST
4.	Molecular Physics II	MolPhys II	6	Lect. + ex.	180 hrs	ST

Requirements for Participation:

Form of Examination:
see with the course

Content:
Fundamentals on an advanced level in experimental physics in Bonn or Cologne

Aims/Skills:
The students will get acquainted with modern research topics

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

Length of Module: 1 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 24 CP out of all 6 Specialization Modules

Module: Specialization: Advanced Experimental Physics

Module No.: physics62a

Course: Physics of Hadrons

Course No.: physics632

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

Requirements for Participation:

Preparation:
Completed B.Sc. in Physics, with experience in electrodynamics, quantum mechanics, atomic- and nuclear 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:
Understanding the many-body structure of hadrons, understanding structural examinations with electromagnetic probes, introduction into experimental phenomenology

Contents of the Course:
Structure Parameters of baryons and mesons; hadronic, electromagnetic and weak probes; size, form factors and structure functions; quarks, asymptotic freedom, confinement, resonances; symmetries and symmetry breaking, hadron masses;
quark models, meson and baryon spectrum; baryon spectroscopy and exclusive reactions; missing resonances, exotic states

Recommended Literature:
B. Povh, K. Rith C. Scholz, F. Zetsche; Teilchen und Kerne (Springer, Heidelberg 6. Aufl. 2004)
Perkins; Introduction to High Energy Physics (Cambridge University Press 4. Aufl. 2000)
K. Gottfried, F. Weisskopf; Concepts of Particle Physics (Oxford University Press 1986)

Module: Specialization: Advanced Experimental Physics

Module No.: physics62a

Course: High Energy Collider Physics

Course No.: physics633

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

Requirements for Participation:

Preparation:
physics611 (Particle Physics)

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

Length of Course:
1 semester

Aims of the Course:
In depth treatment of particle physics at high energy colliders with emphasis on LHC

Contents of the Course:
Kinematics of electron-proton and proton-(anti)proton collisions,
Electron-positron, electron-hadron and hadron-hadron reactions, hard scattering processes,
Collider machines (LEP, Tevatron and LHC) and their detectors (calorimetry and tracking),
the Standard Model of particle physics in the nutshell, fundamental questions posed to the LHC,
spontaneous symmetry breaking and experiment,
QCD and electroweak physics with high-energy hadron colliders,
Physics of the top quark, top cross section and mass measurements,
Higgs Physics at the LHC (search strategies, mass measurement, couplings),
Supersymmetry and beyond the Standard Model physics at the LHC
Determination of CKM matrix elements, CP violation in K and B systems,
Neutrino oscillations

Recommended Literature:
V. D. Barger, R. Phillips; Collider Physics (Addison-Wesley 1996)
R. K. Ellis, W.J. Stirling, B.R. Webber; QCD and Collider Physics (Cambridge University Press 2003)
D. Green; High PT Physics at Hadron Colliders (Cambridge University Press 2004)
C. Berger; Elementarteilchenphysik (Springer, Heidelberg 2nd revised edition 2006)
A. Seiden; Particle Physics A Comprehensive Introduction (Benjamin Cummings 2004)
T. Morii, C.S. Lim; S.N. Mukherjee Physics of the Standard Model and Beyond (World Scientific 2004)

Module: Specialization: Advanced Experimental Physics

Module No.: physics62a

Course: Advanced Topics in High Energy Particle Physics

universitätbonn

Course No.: physics639

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

Requirements for Participation:

Preparation:
physics611 (Particle Physics)

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

Length of Course:
1 semester

Aims of the Course:
To discuss advanced topics of high energy particle physics which are the subject of current research efforts and to deepen understanding of experimental techniques in particle physics.

Contents of the Course:
Selected topics of current research in experimental particle physics. Topics will be updated according to progress in the field. For example:
- LHC highlights
- CP-violation experiments
- Experimental challenges in particle and astroparticle physics
- Current questions in neutrino physics

Recommended Literature:
A. Seiden; Particle Physics: A Comprehensive Introduction (Cummings 2004)
R.K. Ellis, B.R. Webber, W.J. Stirling; QCD and Collider Physics (Cambridge Monographs on Particle Physics 1996)
C. Burgess, G. Moore; The Standard Model: A Primer (Cambridge University Press 2006)
F. Halzen, A. Martin; Quarks and Leptons (J. Wiley, Weinheim 1998)
C. Berger; Elementarteilchenphysik (Springer, Heidelberg, 2. überarb. Aufl. 2006)

Module: Specialization: Advanced Experimental Physics

Module No.: physics62a

Course: Magnetism/Superconductivity

Course No.: physics634

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

Requirements for Participation:

Preparation:

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

Length of Course:
1 semester

Aims of the Course:
To give an introduction to the standard theories of both fields as major example of collective phenomena in condensed-matter physics and comparison with experiments

Contents of the Course:
Magnetism:
orbital and spin magnetism without interactions, exchange interactions, phase transitions, magnetic ordering and domains, magnetism in 1-3 dimensions, spin waves (magnons), itinerant magnetism, colossal magnetoresistance
Superconductivity:
macroscopic aspects, type I and type II superconductors, Ginzburg-Landau theory, BCS theory, Josephson effect, superfluidity, high-temperature superconductivity

Recommended Literature:
L. P. Lévy: Magnetism and superconductivity (Springer; Heidelberg 2000)
P. Mohn: Magnetism in the Solid State - An Introduction (Springer, Heidelberg 2005)
J. Crangle: Solid State Magnetism, Van Nostrand Reinhold (Springer, New York 1991)
C. N. R. Rao, B. Raveau: Colossal Magnetoresistance [...] of Manganese Oxides (World Scientific 2004)
J. F. Annett: Superconductivity, super fluids and condensates (Oxford University Press 2004)
A. Mourachkine: High-Temperature Superconductivity in Cuprates [...] (Springer/Kluwer, Berlin 2002)

Module: Specialization: Advanced Experimental Physics

Module No.: physics62a

Course: Photonics

Course No.: physics641

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

Requirements for Participation:

Preparation:

Form of Testing and Examination:
Examination written or oral (announced at the beginning of the module).
Prerequisite for participation in the exam: successful work within the exercises.

Length of Course:
1 semester

Aims of the Course:
The lecture conveys the physical and technological foundations of laser-based photonics, and enables the students to practically apply their knowledge in research and development.

Contents of the Course:
Foundations: Advanced geometric and wave optics, Fourier optics;
Active and passive devices (Acoustooptics, electrooptics, detectors, imaging)
Advanced optics: Waveguides, Fibers; Photonic Crystals; Metamaterials; Resonators
Laser physics: Light-matter-interaction, principles, operation modes and properties
Nonlinear optics: Second- and third order processes, parametric oscillators, phase matching

Recommended Literature:
D. Meschede; Optics, Light and Lasers (Wiley-VCH, 3rd ed. 2017)
A. Yariv; Photonics: Optical Electronics in Modern Communications (Oxford Univ. Press 6th edition 2006)
B. Saleh, M. Teich; Fundamentals of Photonics (John Wiley & Sons, New York, 1991)
C. Yeh; Applied Photonics (Academic Press, 1994)
R. Menzel; Photonics (Springer, Berlin 2001)

You can not earn credit points for your master examination from this module once you have passed the module physics640: Photonic Devices

Module: Specialization: Advanced Experimental Physics

Module No.: physics62a

Course: Quantum Technology

Course No.: physics642

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

Requirements for Participation:

Preparation:
Quantum mechanics,

Form of Testing and Examination:
Examination written or oral (announced at the beginning of the module).
Prerequisite for participation in the exam: successful work within the exercises.

Length of Course:
1 semester

Aims of the Course:
The aim of the course is to introduce the students to modern applications of quantum physics. Both fundamental concepts of quantum technology as well as platforms for the implementation will be discussed.

Contents of the Course:
Basics of quantum information: Qubits, entanglement, EPR-tests
Quantum communication: Cryptography, teleportation
Quantum computing: circuit computation, paradigms, exotic computation
Quantum simulation
Quantum-enhanced metrology
Selected platforms: Ultracold atoms, single emitters, photonics

Recommended Literature:
S. M Barnett, Quantum information (Oxford University Press 2012)
M.A. Nielsen, I.L. Chuang, Quantum computation and quantum information (Cambridge 2010)
E. Göbel, U. Siegner, Quantum Metrology (Wiley VCH,2015)
W. Nawrocki, Introduction to Quantum Metrology (Springer 2019)
M. Lewenstein, A. Sanpera, V. Ahufinger, Ultracold atoms in optical lattices Simulating quantum many-body systems (Oxford University Press 2012)

Module: Specialization: Advanced Experimental Physics

Module No.: physics62a

Course: Molecular Physics II

Course No.:

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

Requirements for Participation:

Preparation:
Atomic Physics, Molecular Physics and Quantum Mechanics at the level of the bachelor courses in physics, Molecular Physics I

Form of Testing and Examination:
Oral Examination

Length of Course:
1 semester

Aims of the Course:
In the second part of the core courses more complex issues of molecular spectra are introduced. The students will be enabled to analyze spectra of complex molecules which are subject to couplings between electronic, vibrational and rotational motions.
In the special courses basic and advanced molecular physics are applied to atmospherical and astronomical environments.
This module prepares for topics of current research in molecular physics and provides the basis for the preparation of the master thesis.

Contents of the Course:
- Vibrational modes of polyatomic molecules
- Fundamentals of point group symmetry
- Vibrational dipole moment and selection rules
- Characteristic ro-vibrational spectra of selected molecules
- Breakdown of Born-Oppenheimer Approximation
- Coupling of rotation and vibration
- Coupling of angular momenta in molecular physics

Recommended Literature:
Bernath, "Spectra of Atoms and Molecules", Oxford University Press)
Townes Schawlow, "Microwave Spectroscopy" (Dover Publications)
Gordy & Cook, Microwave Spectra" (Wiley)
Engelke, "Aufbau der Moleküle" (Teubner)
P. R. Bunker and Per Jensen: "Molecular Symmetry and Spectroscopy, 2nd Edition", (NRC Research Press, Ottawa)

Module No.: physics61b
Credit Points (CP): 6
Category: Elective
Semester: 1.

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Specialization: Applied Physics

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	t.b.a.					

Requirements for Participation:

Form of Examination:
see with the course

Content:
Fundamentals in applied physics in Bonn or Cologne

Aims/Skills:
The students will get acquainted with modern research topics

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

Length of Module: 1 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 24 CP out of all 6 Specialization Modules

Module No.: physics62b
Credit Points (CP): 6
Category: Elective
Semester: 2.

Fachgruppe Physik und Astronomie Universität Bonn

Module: Specialization: Advanced Applied Physics

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	t.b.a.					

Requirements for Participation:

Form of Examination:
see with the course

Content:
Fundamentals on an advanced level in applied physics in Bonn or Cologne

Aims/Skills:
The students will get acquainted with modern research topics

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

Length of Module: 1 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 24 CP out of all 6 Specialization Modules

Module No.: physics61c
Credit Points (CP): 7
Category: Elective
Semester: 1.

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Specialization: Theoretical Physics

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
Theoretical Physics						
1.	Theoretical Particle Physics	physics615	7	Lect. + ex.	210 hrs	WT
2.	Theoretical Hadron Physics	physics616	7	Lect. + ex.	210 hrs	WT
3.	Theoretical Condensed Matter Physics	physics617	7	Lect. + ex.	210 hrs	WT
4.	Solid State Theory I	TheoSolidSt	6	Lect. + ex.	180 hrs	WT

Requirements for Participation:

Form of Examination:
see with the course

Content:
Fundamentals in theoretical physics in Bonn or Cologne

Aims/Skills:
Mit den Spezialisierungsvorlesungen wird die Möglichkeit eröffnet, sich in einer bzw. mehreren der in Bonn vertretenen Forschungsrichtungen zu spezialisieren.
The students will get acquainted with modern research topics

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

Length of Module: 1 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 24 CP out of all 6 Specialization Modules

Module: Specialization: Theoretical Physics

Module No.: physics61c

Course: Theoretical Particle Physics

Course No.: physics615

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

Requirements for Participation:

Preparation:
Advanced quantum theory (physics606)
Quantum field theory (physics755)
Group theory (physics751)

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 standard model of elementary particle physics and its extensions (unified theories)

Contents of the Course:
Classical field theory, gauge theories, Higgs mechanism;
Standard model of strong and electroweak interactions;
Supersymmetry and the supersymmetric extension of the standard model;
Grand unified theories (GUTs);
Neutrino physics;
Cosmological aspects of particle physics (dark matter, inflation)

Recommended Literature:
T. P. Cheng, L.F. Li: Gauge theories of elementary particle physics (Clarendon Press, Oxford 1984)
M. E. Peskin, D.V. Schroeder; An introduction to quantum field theory (Addison Wesley, 1995)
J. Wess; J. Bagger; Supersymmetry and supergravity (Princeton University Press 1992)

Module: Specialization: Theoretical Physics

Module No.: physics61c

Course: Theoretical Hadron Physics

Course No.: physics616

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

Requirements for Participation:

Preparation:
Advanced quantum theory (physics606)
Quantum field theory (physics755)
Group theory (physics751)

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 theory of strong interaction, hadron structure and dynamics

Contents of the Course:
Meson and Baryon Spectra: Group theoretical Classification, Simple Quark Models
Basics of Quantum Chromodynamics: Results in Perturbation Theory
Effective Field Theory
Bethe-Salpeter Equation

Recommended Literature:
F. E. Close, An Introduction to Quarks and Partons (Academic Press 1980)
F. Donoghue, E. Golowich, B.R. Holstein; Dynamics of the Standard Model (Cambridge University Press 1994)
C. Itzykson, J.-B. Zuber; Quantum Field Theory (Dover Publications 2005)
S. Weinberg; The Quantum Theory of Fields (Cambridge University Press 1995)

Module: Specialization: Theoretical Physics

Module No.: physics61c

Course: Theoretical Condensed Matter Physics

Course No.: physics617

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

Requirements for Participation:

Preparation:
Advanced Quantum Theory (physics606)
Quantum Field Theory (physics755)
Group theory (physics751)

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 theoretical standard methods and understanding important phenomena in the Physics of Condensed Matter

Contents of the Course:
Crystalline Solids: Lattice structure, point groups, reciprocal lattice
Elementary excitations of a crystal lattice: phonons
Electrons in a lattice; Bloch theorem, band structure
Fermi liquid theory
Magnetism
Symmetries and collective excitations in solids
Superconductivity
Integer and fractional quantum Hall effects

Recommended Literature:
N. W. Ashcroft, N.D. Mermin, Solid State Physics (Saunders College 1976)
P. M. Chaikin, T.C. Lubensky; Principles of Condensed Matter Physics (Cambridge University Press 1997)
W. Nolting; Grundkurs Theoretische Physik Band 7: Vielteilchentheorie (Springer, Heidelberg 2002)
Ch. Kittel; Quantentheorie der Festkörper (Oldenburg Verlag, München 3. Aufl. 1989)

Module: Specialization: Theoretical Physics

Module No.: physics61c

Course: Solid State Theory I

Course No.:

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

Requirements for Participation:

Preparation:
training in theoretical physics at the B.Sc. level, experimental solid state physics

Form of Testing and Examination:
written or oral examination

Length of Course:
1 semester

Aims of the Course:
this course gives an introduction to the physics of electrons and phonons in solids together with theoretical concepts and techniques as applied to these systems.

Contents of the Course:
The lecture investigates basic concepts to describe solids and their excitations. Various applications are discussed with emphasis on experimental and theoretical research directions of the physics department in Cologne.

Recommended Literature:
Ashcroft/ Mermin: "Solid State Physics"

Module No.: physics62c
Credit Points (CP): 7
Category: Elective
Semester: 2.

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Specialization: Advanced Theoretical Physics

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
Theoretical Physics						
1.	Advanced Theoretical Particle Physics	physics636	7	Lect. + ex.	210 hrs	ST
2.	Advanced Theoretical Hadron Physics	physics637	7	Lect. + ex.	210 hrs	ST
3.	Advanced Theoretical Condensed Matter Physics	physics638	7	Lect. + ex.	210 hrs	ST

Requirements for Participation:

Form of Examination:
see with the course

Content:
Fundamentals on an advanced level in theoretical physics in Bonn or Cologne

Aims/Skills:
The students will get acquainted with modern research topics

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

Length of Module: 1 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 24 CP out of all 6 Specialization Modules

Module: Specialization: Advanced Theoretical Physics

Module No.: physics62c

Course: Advanced Theoretical Particle Physics

Course No.: physics636

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

Requirements for Participation:

Preparation:
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 methods of theoretical high energy physics beyond the standard model, in particular supersymmetry and extra dimensions in regard to current research

Contents of the Course:
Introduction to supersymmetry and supergravity,
Supersymmetric extension of the electroweak standard model,
Supersymmetric grand unification,
Theories of higher dimensional space-time,
Unification in extra dimensions

Recommended Literature:
J. Wess; J. Bagger; Supersymmetry and supergravity (Princeton University Press 1992)
H. P. Nilles, Supersymmetry, Supergravity and Particle Physics, Physics Reports 110 C (1984) 1
D. Bailin; A. Love; Supersymmetric Gauge Field Theory and String Theory (IOP Publishing Ltd. 1994)
M. F. Sohnius; Introducing supersymmtry, (Phys.Res. 128 C (1985) 39)
P. Freund; Introduction to Supersymmetry (Cambridge University Press 1995)

Module: Specialization: Advanced Theoretical Physics

Module No.: physics62c

Course: Advanced Theoretical Hadron Physics

Course No.: physics637

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

Requirements for Participation:

Preparation:
physics616 (Theoretical Hadron Physics)

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

Length of Course:
1 semester

Aims of the Course:
Survey of methods of theoretical hadron physics in regard to current research

Contents of the Course:
Quantum Chromodynamics: Nonperturbative Results, Confinement
Lattice Gauge Theory
Chiral Perturbation Theory
Effective Field Theory for Heavy Quarks

Recommended Literature:
F. E. Close; An Introduction Quarks and Partons (Academic Press 1980)
F. Donoghue, E. Golowich, B. R. Holstein, Dynamics of the Standard Model (Cambridge University Press 1994)
C. Itzykson, J.-B. Zuber; Quantum Field Theory (Dover Publications 2006)
A. V. Manohar, M. B. Wise; Heavy Quark Physics (Cambridge University Press 2000)
S. Weinberg; The Quantum Theory of Fields (Cambridge University Press 1995)

Module: Specialization: Advanced Theoretical Physics

Module No.: physics62c

Course: Advanced Theoretical Condensed Matter Physics

Course No.: physics638

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

Requirements for Participation:

Preparation:
physics617 (Theoretical Condensed Matter Physics)

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

Length of Course:
1 semester

Aims of the Course:
Survey of methods of theoretical condensed matter physics and their application to prominent examples in regard to current research

Contents of the Course:
Bosonic systems:
Bose-Einstein condensation
Photonics

Quantum dynamics of many-electrons systems:
Feynman diagram technique for many-particle systems at finite temperature
Quantum magnetism, Kondo effect, Renormalization group techniques
Disordered systems: Electrons in a random potential
Superconductivity

Recommended Literature:
A. A. Abrikosov, L.P. Gorkov; Methods of Quantum Field Theory in Statistical Physics (Dover, New York 1977)
W. Nolting; Grundkurs Theoretische Physik Band 7: Vielteilchentheorie (Springer, Heidelberg 2002)
A. C. Hewson, The Kondo Problem to Heavy Fermions (Cambridge University Press, 1997)
C. Itzykson, J.-M. Drouffe; Statistical Field Theory (Cambridge University Press 1991)
J. R. Schrieffer; Theory of Superconductivity (Benjamin/Cummings, Reading/Mass, 1983)

Module No.: physics65a
Credit Points (CP): 4
Category: Elective
Semester: 2.

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Seminar: Experimental Physics

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Seminars on Current Topics in Experimental Physics		4	seminar	120 hrs	WT/ST

Requirements for Participation:

Form of Examination:
Presentation

Content:
Topics in modern experimental physics covered by the research groups, including current journal literature

Aims/Skills:
The students shall learn to explore a specific scientific topic with the help of libraries and electronic media. The presentation must be concise and structured

Course achievement/Criteria for awarding cp's:
regular participation and active contribution

Length of Module: 1 semester

Maximum Number of Participants: 20 per seminar

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

Useable for:
Masterstudiengang Physik, Pflicht, Semester: 1-2

Module No.: physics65b
Credit Points (CP): 4
Category: Elective
Semester: 2.

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Seminar: Applied Physics

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Seminars on Current Topics in Applied Physics		4	seminar	120 hrs	WT/ST

Requirements for Participation:

Form of Examination:
Presentation

Content:
Topics in modern applied physics covered by the research groups, including current journal literature

Aims/Skills:
The students shall learn to explore a specific scientific topic with the help of libraries and electronic media. The presentation must be concise and structured

Course achievement/Criteria for awarding cp's:
regular participation and active contribution

Length of Module: 1 semester

Maximum Number of Participants: 20 per seminar

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

Useable for:
Masterstudiengang Physik, Pflicht, Semester: 1-2

Module No.: physics65c
Credit Points (CP): 4
Category: Elective
Semester: 2.

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Seminar: Theoretical Physics

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Seminars on Current Topics in Theoretical Physics		4	seminar	120 hrs	WT/ST

Requirements for Participation:

Form of Examination:
Presentation

Content:
Topics in modern theoretical physics covered by the research groups, including current journal literature

Aims/Skills:
The students shall learn to explore a specific scientific topic with the help of libraries and electronic media. The presentation must be concise and structured

Course achievement/Criteria for awarding cp's:
regular participation and active contribution

Length of Module: 1 semester

Maximum Number of Participants: 20 per seminar

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

Useable for:
Masterstudiengang Physik, Pflicht, Semester: 1-2

Module No.: physics70a
Credit Points (CP): 3-6
Category: Elective
Semester: 1.-2.

Fachgruppe Physik und Astronomie Universität Bonn

Module: Elective Advanced Lectures: Experimental Physics

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Selected courses from catalogue type "E" (Experimental) or "E/A" (E/Applied)	see catalogue	3-6	see catalogue	90-180 hrs	ST/WT
2.	Also possible classes from M.Sc. in Astrophysics					

Requirements for Participation:
none

Form of Examination:
see with the course

Content:
Advanced lectures in experimental 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

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: Particle Astrophysics and Cosmology (E)

Course No.: physics711

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

Requirements for Participation:

Preparation:
physics611 (Particle Physics), useful: Lectures Observational Astronomy

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

Length of Course:
1 semester

Aims of the Course:
Basics of particle astrophysics and cosmology

Contents of the Course:
Observational Overview (distribution of galaxies, redshift, Hubble expansion, CMB, cosmic distance latter, comoving distance, cosmic time, comoving distance and redshift, angular size and luminosity distance); Standard Cosmology (cosmological principle, expansion scale factor, curved space-time, horizons, Friedmann-Equations, cosmological constant, cosmic sum rule, present problems); Particle Physics relevant to cosmology (Fundamental Particles and their Interactions, quantum field theory and Lagrange formalism, Gauge Symmetry, spontaneous symmetry breaking and Higgs mechanism, parameters of the Standard Model, Running Coupling Constants, CP Violation and Baryon Asymmetry, Neutrinos); Thermodynamics in the Universe (Equilibrium Thermodynamics and freeze out, First Law and Entropy, Quantum Statistics, neutrino decoupling, reheating, photon decoupling); Nucleosynthesis (Helium abundance, Fusion processes, photon/baryon ratio)
Dark Matter (Galaxy Rotation Curves, Clusters of Galaxies, Hot gas, Gravitational lensing, problems with Cold Dark Matter Models, Dark Matter Candidates); Inflation and Quintessence; Cosmic Microwave Background (origin, intensity spectrum, CMB anisotropies, Temperature correlations, power spectrum, cosmic variance, density and temperature fluctuations, causality and changing horizons, long and short wavelength modes, interpretation of the power spectrum)

Recommended Literature:
A. Liddle; An Introduction to Modern Cosmology (Wiley & Sons 2. Ed. 2003)
E. Kolb, M. Turner; The Early Universe (Addison Wesley 1990)
J. Peacock; Cosmological Physics (Cambridge University Press 1999)

Modules:

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

Course: Advanced Electronics and Signal Processing (E/A)

Course No.: physics712

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

Requirements for Participation:

Preparation:
Electronics laboratory of the B.Sc. in physics programme
Recommended: module nuclear and particle physics of the B.Sc. programme

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

Length of Course:
1 semester

Aims of the Course:
Comprehension of the basics of electronics circuits for the processing of (detector) signals, mediation of the basics of experimental techniques regarding electronics and micro electronics as well as signal processing

Contents of the Course:
The physics of electronic devices, junctions, transistors (BJT and FET), standard analog and digital circuits, amplifiers, elements of CMOS technologies, signal processing, ADC, DAC, noise sources and noise filtering, coupling of electronics to sensors/detectors, elements of chip design, VLSI electronics, readout techniques for detectors

Recommended Literature:
P. Horowitz, W. Hill; The Art of Electronics (Cambridge University Press 2. Aufl. 1989)
S. Sze; The Physics of Semiconductor Devices (Wiley & Sons 1981)
H. Spieler, Semiconductor detector system (Oxford University Press 2005))
J. Krenz; Electronics Concepts (Cambridge University Press 2000)

Modules:

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

Course: Particle Detectors and Instrumentation (E/A)

Course No.: physics713

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

Requirements for Participation:

Preparation:
Completed B.Sc. in Physics, with experience in quantum mechanics, atomic- and nuclear 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:
Designing an experiment in photoproduction on pi-0, selection and building of appropriate detectors, set-up and implementation of an experiment at ELSA

Contents of the Course:
Quark structure of mesons and baryons, nucleon excitation; electromagnetic probes, electron accelerators, photon beams, relativistic kinematics interaction of radiation with matter, detectors for photons, leptons and hadrons; laboratory course: setup of detectors and experiment at ELSA

Recommended Literature:
B. Povh, K. Rith, C. Scholz, F. Zetsche; Teilchen und Kerne (Springer, Heidelberg 6. Aufl. 2004)
Perkins; Introduction to High Energy Physics (Cambridge University Press 4. Aufl. 2000)
W. R. Leo; Techniques for Nuclear and Particle Detection (Springer, Heidelberg 2. Ed. 1994)
K. Kleinknecht; Detektoren für Teilchenstrahlung (Teubner, Wiesbaden 4. überarb. Aufl. 2005)

Modules:

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

Course: Advanced Accelerator Physics (E/A)

Course No.: physics714

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

Requirements for Participation:

Preparation:
Accelerator Physics (physics612)

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 of the physics of synchrotron radiation and its influence on beam parameters
Basic knowledge of collective phenomena in particle accelerators
General knowledge of applications of particle accelerators (research, medicine, energy management)

Contents of the Course:
Synchrotron radiation:
radiation power, spatial distribution, spectrum, damping, equilibrium beam emittance, beam lifetime
Space-charge effects:
self-field and wall effects, beam-beam effects, space charge dominated beam transport, neutralization of beams by ionization of the residual gas
Collective phenomena:
wake fields, wake functions and coupling impedances, spectra of a stationary and oscillating bunches, bunch interaction with an impedance, Robinson instability
Applications of particle accelerators:
medical accelerators, neutrino facilities, free electron lasers, nuclear waste transmutation, etc.

Recommended Literature:
F. Hinterberger; Physik der Teilchenbeschleuniger und Ionenoptik (Springer, Heidelberg 1997)
H. Wiedemann; Particle Accelerator Physics (Springer, Heidelberg 2 Aufl. 1999)
K. Wille; Physik der Teilchenbeschleuniger und Synchrotronstrahlungsquellen (Teubner, Wiesbaden 2. Aufl. 1996)
D. A. Edwards, M.J. Syphers; An Introduction to the Physics of High Energy Accelerators (Wiley & Sons 1993)
A. Chao; Physics of Collective Beam Instabilities in High Energy Accelerators (Wiley & Sons 1993)
Script of the Lecture Particle Accelerators (physics612)
http://www-elsa.physik.uni-bonn.de/~hillert/Beschleunigerphysik/

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: Experiments on the Structure of Hadrons (E)

Course No.: physics715

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

Requirements for Participation:

Preparation:
Completed B.Sc. in Physics, with experience in quantum mechanics, atomic- and nuclear 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:
Understanding the structure of the nucleon, understanding experiments on baryon-spectroscopy, methods of identifying resonance contributions, introduction into current issues in meson-photoproduction

Contents of the Course:
Discoveries in hadron physics, quarks, asymptotic freedom and confinement; multiplets, symmetries, mass generation; quark models, baryon spectroscopy, formation and decay of resonances, meson photoproduction; hadronic molecules and exotic states

Recommended Literature:
Perkins, Introduction to High Energy Physics (Cambridge University Press 4. Aufl. 2000)
K. Gottfried, F. Weisskopf; Concepts of Particle Physics (Oxford University Press 1986)
A. Thomas, W. Weise, The Structure of the Nucleon (Wiley-VCH, Weinheim, 2001)

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: universitätbonn Statistical Methods of Data Analysis (E)

Course No.: physics716

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

Requirements for Participation:

Preparation:

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

Length of Course:
1 semester

Aims of the Course:
Provide a foundation in statistical methods and give some concrete examples of how the methods are applied to data analysis in particle physics experiments

Contents of the Course:
Fundamental concepts of statistics, probability distributions, Monte Carlo methods, fitting of data, statistical and systematic errors, error propagation, upper limits, hypothesis testing, unfolding

Recommended Literature:
R. Barlow: A Guide to the Use of Statistical Methods in the Physical Sciences; J. Wiley Ltd. Wichester 1993
S. Brandt: Datenanalyse (Spektrum Akademischer Verlag, Heidelberg 4. Aufl. 1999)

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: High Energy Physics Lab (E)

Course No.: physics717

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

Requirements for Participation:

Preparation:
Recommended: B.Sc. in physics, physics611 (Particle Physics) or physics618 (Physics of Particle Detectors)

Form of Testing and Examination:
Credit points can be obtained after completion of a written report or, alternatively, a presentation in a meeting of the research group.

Length of Course:
4-6 weeks

Aims of the Course:
This is a research internship in one of the high energy physics research groups which prepare and carry out experiments at external accelerators. The students deepen their understanding of particle and/or detector physics by conducting their own small research project as a part-time member of one of the research groups. The students learn methods of scientific research in particle physics data analysis, in detector development for future colliders or in biomedical imaging (X-FEL) and present their work at the end of the project in a group meeting.

Contents of the Course:
Several different topics are offered among which the students can choose. Available projects can be found at http://heplab.physik.uni-bonn.de. For example:
- Analysis of data from one of the large high energy physics experiments (ATLAS, DØ, ZEUS)
- Investigation of low-noise semiconductor detectors using cosmic rays, laser beams or X-ray tubes
- Study of particle physics processes using simulated events
- Signal extraction and data mining with advanced statistical methods (likelihoods, neural nets or boosted decision trees)

Recommended Literature:
Will be provided by the supervisor

Modules:

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

Course: Programming in Physics and Astronomy with C++ or Python (E/A)

Course No.: physics718

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

Requirements for Participation:

Preparation:
Basic knowledge of programming and knowledge of simple C/C++ or Python constructs.

Form of Testing and Examination:
C/C++ part: Requirements for the examination (written or oral): successful work with the exercises.
Python part: Requirements for examination: successful implementation of the scientific projects in Python during the semester.

Length of Course:
1 semester

Aims of the Course:
C++ part: In-depth understanding of C++ and its applications in particle physics. Discussion of advanced features of C++ using examples from High Energy Physics. The course is intended for students with some background in C++ or for advanced students who wish to apply C++ in their graduate research.
Python part: Effective and flexible program solving with the easy-to-learn, high level programming language Python. The course addresses master and PhD students with prior Python-programming knowledge as taught in the bachelor course physics131.

Contents of the Course:
C++ part: - Basic ingredients of C++, - Object orientation: classes, inheritance, polymorphism, - How to solve physics problems with C++, - Standard Template Library, - C++ in data analysis, example: the ROOT library, - C++ and large scale calculations, - How to write and maintain complex programs, - Parallel computing and the Grid, - Debugging and profiling
Python part: - In-depth introduction to Python based on prior programming experience, - Introduction to numpy arrays (primary Python data structure for scientific computing), - Introduction to scientific-Python modules (scipy, astropy), - Interactive work / development with Python (ipython), - Web interaction with Python (jupyter notebooks, web and database queries), - Plotting with Python (the matplotlib module)

Recommended Literature:
Eckel: Thinking in C++, Prentice Hall 2000.
Lippman, Lajoie, Moo: C++ Primer, Addison-Wesley 2000.
Deitel and Deitel, C++ how to program, Prentice Hall 2007.
Stroustrup, The C++ Programming Language, Addison-Wesley 2000.

- The course is given in the summer term and alternates between C++ and Python
- The course can only be taken once for credit points.

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: Intensive Week: Advanced Topics in High Energy Physics (E)

Course No.: physics719

Category	Type	Language	Teaching hours	CP	Semester
Elective	Combined lecture, seminar, lab course	English	2	3	WT/ST

Requirements for Participation:

Preparation:
Fundamentals of particle physics

Form of Testing and Examination:
Seminar talk

Length of Course:
1 - 2 weeks

Aims of the Course:
This course is about an advanced, current topic in particle physics. The students will gain insights into recent developments in particle physics and participate in lectures, seminars talks and laboratory projects.

Contents of the Course:
As announced in the course catalogue. The main topic will vary from semester to semester.

Recommended Literature:
Will be given in the lecture.

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: Physics with Antiprotons (E)

Course No.: physics720

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

Requirements for Participation:

Preparation:
Completed B.Sc. in Physics, with experience in quantum mechanics, atomic- and nuclear physics

Form of Testing and Examination:
Written or oral examination

Length of Course:
1 semester

Aims of the Course:
Insight in current research topics with antiprotons, understanding experimental methods in particle and nuclear physics, understanding interrelations between different fields of physics such as hadron physics, (astro-)particle physics, atomic physics

Contents of the Course:
Matter-antimatter asymmetry, test of the standard model, anti-hydrogen, anti-protonic atoms, antiproton beams, key issues in hadron physics with antiprotons, planned research facilities (FAIR) and experiments (PANDA)

Recommended Literature:
B. Povh, K. Rith, C. Scholz, F. Zetsche; Teilchen und Kerne (Springer, Heidelberg 8. Aufl. 2009)
D.H. Perkins; Introduction to High Energy Physics (Cambridge University Press 4. Aufl. 2000)
further literature will be given in the lecture

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: Intensive Week: Advanced Topics in Hadron Physics (E)

Course No.: physics721

Category	Type	Language	Teaching hours	CP	Semester
Elective	Combined lecture, seminar, lab course	English	2	3	WT/ST

Requirements for Participation:

Preparation:
Fundamentals of hadron physics

Form of Testing and Examination:
Presentation, working group participation

Length of Course:
1 - 2 weeks

Aims of the Course:
This course will convey recent topics in hadron physics. Guided by lectures, original publications and tutors, the students will prepare a proposal for a planned or recent experiment. The class will not only focus on the experimental aspects, but also on the theoretical motivation for the experiment.

Contents of the Course:
As announced in the course catalogue. The main topics will vary from semester to semester.

Recommended Literature:
Will be given in the lecture

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: Advanced Gaseous Detectors - Theory and Practice (E)

Course No.: physics722

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

Requirements for Participation:

Preparation:
Completed B.Sc. in physics, with experience in electrodynamics, quantum mechanics, nuclear and particle physics, physics618 (Physics of Particle Detectors)

Form of Testing and Examination:
Form of examination: written or oral report

Length of Course:
1 semester

Aims of the Course:
- Design, construction, commissioning and characterization of a modern gaseous particle detector
- Simulations: GARFIELD, GEANT, FE-Methods, etc.
- Signals, Readout electronics and Data Acquisition
- Data analysis: pattern recognition methods, track fitting
- Scientific writing: report

Contents of the Course:
- Signal formation in detectors
- Microscopic processes in gaseous detectors
- Readout electronics
- Tools for detector design and simulation
- Performance criteria
- Laboratory course: commissioning of detector with sources, beam test at accelerator
- Track reconstruction

Recommended Literature:
http://root.cern.ch
http://garfieldpp.web.cern.ch/garfieldpp/
Blum, Rolandi, Riegler: Particle Detection with Drift Chambers
Spieler: Semiconductor Detector Systems

Modules:	physics70a	**Elective Advanced Lectures: Experimental Physics**
	physics70b	**Elective Advanced Lectures: Applied Physics**

Course: Hands-on Seminar: Detector Construction (E/A)

Course No.: physics723

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

Requirements for Participation:
Basic knowledge of particle physics

Preparation:
physics618 is helpful but not mandatory

Form of Testing and Examination:
Credit points can be obtained after successful construction and operation of the detector and preparing a written and/or oral report on a specific task

Length of Course:
1 semester

Aims of the Course:
Students will design, construct, assemble and operate a particle detector.

Contents of the Course:
Students will construct, assemble and commission a particle detector. They will gain hands-on experience on detector construction. The students organize and execute the tasks of the project in personal responsibility. This includes many tasks common to more complex research or industrial projects. Topics include:

- order the needed detector components
- prepare CAD drawings
- prepare PCB layout
- develop electronic circuits
- produce and assemble detector parts
- vacuum technology
- cooling technology
- organize the work effort in personal responsibility
- communicate with team members and technical staff

Recommended Literature:
H. Kolanoski, N. Wermes, Teilchendetektoren, (Springer, Heidelberg, 2016)
W. R. Leo; Techniques for Nuclear and Particle Detection (Springer, Heidelberg 2. Ed. 1994)
K. Kleinknecht; Detektoren für Teilchenstrahlung (Teubner, Wiesbaden 4. überarb. Aufl. 2005)

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: Advanced Methods of Data Analysis (E)

Course No.: physics724

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

Requirements for Participation:
The course builds on the knowledge taught in physics716 Statistical Methods of Data Analysis and is designed as a follow-up course. Participants need to have a working knowledge of the basics of statistical data analysis, including parameter estimation and statistical tests.

Preparation:
Students should have a basic knowledge of either C++ or python programming languages. There will be opportunity during the course to develop programming skills through applications of data analysis.

Form of Testing and Examination:
The examination can be done either through a written exam or by written term papers as communicated at the beginning of the course.

Length of Course:
1 semester

Aims of the Course:
This course teaches advanced techniques of statistical data analysis. Its goal is to enable the participants to contribute to state of the art data analysis projects, for example during their master thesis, and to enable them to conduct their own research into statistical data analysis methods.

Contents of the Course:
Parametric likelihood fits, constraint optimisation, state space models, non-parametric density estimation, unfolding, model validation, introduction to machine learning, classification, adaptive basis function models, ensemble learning, deep generative models

Examples from high energy and hadronic physics.

Recommended Literature:
Elements of statistical learning, 2nd Edition, Hastie, Tibshirani & Friedman, Springer 2017
Data Analysis in High Energy Physics, Behnke et Al. , Wiley-VCH 2013
Statistical Analysis Techniques in Particle Physics, Narsky & Porter, Wiley-VCH 2013
Machine Learning, A Probabilistic Perspective, Murphy, MIT Press 2012

Modules:

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

Course: Scientific Programming with Python (E/A)

Course No.: physics725

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	6	ST

Requirements for Participation:

Preparation:
Prior knowledge of any programming language (C/C++, Java, Python, ...)

Form of Testing and Examination:
Successful implementation of scientific projects in Python during the semester

Length of Course:
1 semester

Aims of the Course:
Effective and flexible program solving with the easy-to-learn, high-level programming language Python. The course addresses master and PhD students with prior programming knowledge as taught in the bachelor course physics131.

Contents of the Course:
In-depth introduction to the Python programming language; Introduction to numpy arrays (primary Python data structure for scientific computing); Introduction to scientific-Python modules (scipy, astropy);
Interactive work / development with Python (ipython); Web interaction with Python (jupyter notebooks, web and database queries);
Plotting with Python (the matplotlib module), Introduction to writing own scientific Python-modules and Object-oriented programming, Collaborative code development and version control (git, github)

Recommended Literature:
All necessary materials are made available online via the eCampus platform

Credit points can only be earned from one exam out of physics718 and physics725

Modules:

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

Course: Low Temperature Physics (E/A)

Course No.: physics731

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

Requirements for Participation:

Preparation:
Elementary thermodynamics; principles of quantum mechanics; introductory lecture on solid state 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:
Experimental methods at low (down to micro Kelvin) temperatures; methods of refrigeration; thermometry; solid state physics at low temperatures

Contents of the Course:
Thermodynamics of different refrigeration processes, liquefaction of gases; methods to reach low (< 1 Kelvin) temperatures: evaporation cooling, He-3-He-4 dilution cooling, Pomeranchuk effect, adiabatic demagnetisation of atoms and nuclei; thermometry at low temperatures (e.g. helium, magnetic thermometry, noise thermometry, thermometry using radioactive nuclei); principles for the construction of cryostats for low temperatures

Recommended Literature:
O.V. Lounasmaa; Experimental Principles and Methods Below 1K (Academic Press, London 1974)
R.C. Richardson, E.N. Smith; Experimental Techniques in Condensed Matter Physics at Low Temperatures (Addison-Wesley 1988)
F. Pobell, Matter and Methods at Low Temperatures (Springer-Verlag, Heidelberg 2. Aufl. 1996)

Modules:

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

Course: Optics Lab (E/A)

Course No.: physics732

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

Requirements for Participation:

Preparation:

Form of Testing and Examination:
Credit points can be obtained after completion of a written report.

Length of Course:
4-6 weeks

Aims of the Course:
The student learns to handle his/her own research project within one of the optics groups

Available projects and contact information can be found at: http://www.iap.uni-bonn.de/opticslab/

Contents of the Course:
Practical training/internship in a research group, which can have several aspects:
- setting up a small experiment
- testing and understanding the limits of experimental components
- simulating experimental situations

Recommended Literature:
Will be given by the supervisor

Modules:

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

Course: Holography (E/A)

Course No.: physics734

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

Requirements for Participation:

Preparation:

Form of Testing and Examination:
Written or oral examination

Length of Course:
1 semester

Aims of the Course:
The goal of the course is to provide in-depth knowledge and to provide practical abilities in the field of holography as an actual topic of applied optics

Contents of the Course:
The course will cover the basic principle of holography, holographic recording materials, and applications of holography. In the first part the idea behind holography will be explained and different hologram types will be discussed (transmission and reflection holograms; thin and thick holograms; amplitude and phase holograms; white-light holograms; computer-generated holograms; printed holograms). A key issue is the holographic recording material, and several material classes will be introduced in the course (photographic emulsions; photochromic materials; photo-polymerization; photo-addressable polymers; photorefractive crystals; photosensitive inorganic glasses). In the third section several fascinating applications of holography will be discussed (art; security-features on credit cards, banknotes, and passports; laser technology; data storage; image processing; filters and switches for optical telecommunication networks; novelty filters; phase conjugation ["time machine"]; femtosecond holography; space-time conversion). Interested students can also participate in practical training. An experimental setup to fabricate own holograms is available

Recommended Literature:
Lecture notes;
P. Hariharan; Optical Holography - Principles, Techniques, and Applications (Cambridge University Press, 2nd Edition, 1996)
P. Hariharan; Basics of Holography (Cambridge University Press 2002)
J. W. Goodman; Introduction to Fourier Optics (McGraw-Hill Education - Europe 2nd Ed. 2000)
A. Yariv; Photonics (Oxford University Press 6th Ed. 2006)

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: Laser Cooling and Matter Waves (E)

universitätbonn

Course No.: physics735

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

Requirements for Participation:

Preparation:
Basic thermodynamics: fundamentals of quantum mechanics, fundamentals of solid state physics

Form of Testing and Examination:
Written or oral examination

Length of Course:
1 semester

Aims of the Course:
The in-depth lecture shows, in theory and experiments, the fundamentals of laser cooling. The application of laser cooling in atom optics, in particular for the preparation of atomic matter waves, is shown. New results in research with degenerated quantum gases enable us to gain insight into atomic many particle physics

Contents of the Course:
Outline: Light-matter interaction; mechanic effects of light; Doppler cooling; polarization gradient cooling, magneto-optical traps; optical molasses; cold atomic gases; atom interferometry; Bose-Einstein condensation of atoms; atom lasers; Mott insulator phase transitions; mixtures of quantum gases; fermionic degenerate gases

Recommended Literature:
P. v. d. Straten, H. Metcalf; Laser Cooling (Springer, Heidelberg 1999)

Modules:

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

Course: universitätbonn Crystal Optics (E/A)

Course No.: physics736

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

Requirements for Participation:

Preparation:

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:
Because of their aesthetic nature crystals are termed "flowers of mineral kingdom". The aesthetic aspect is closely related to the symmetry of the crystals which in turn determines their optical properties. It is the purpose of this course to stimulate the understanding of these relations. The mathematical and tools for describing symmetry and an introduction to polarization optics will be given before the optical properties following from crystal symmetry are discussed. Particular emphasis will be put on the magneto-optical properties of crystals in magnetic internal or external fields. Advanced topics such as the determination of magnetic structures and interactions by nonlinear magneto-optics will conclude the course

Contents of the Course:
Crystal classes and their symmetry; basic group theory; polarized light; optical properties in the absence of fields; electro-optical properties; magneto-optical properties: Faraday effect, Kerr effect, magneto-optical materials and devices, semiconductor magneto-optics, time-resolved magneto-optics, nonlinear magneto-optics

Recommended Literature:
R. R. Birss, Symmetry and Magnetism, North-Holland (1966)
R. E. Newnham: Properties of Materials: Anisotropy, Symmetry, Structure, Oxford University (2005)
A. K. Zvezdin, V. A. Kotov: Modern Magnetooptics & Magnetooptical Materials, Taylor/Francis (1997)
Y. R. Shen: The Principles of Nonlinear Optics, Wiley (2002)
K. H. Bennemann: Nonlinear Optics in Metals, Oxford University (1999)

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: Intensive Week: Advanced Topics in Photonics and Quantum Optics (E)

Course No.: physics737

Category	Type	Language	Teaching hours	CP	Semester
Elective	Combined lecture, seminar, lab course	English	2	3	WT/ST

Requirements for Participation:

Preparation:
Fundamentals of optics, fundamentals of quantum mechanics

Form of Testing and Examination:
Seminar or oral examination

Length of Course:
1 - 2 weeks

Aims of the Course:
The intensive course will convey the basics of a recent topic in photonics or quantum optics in theory and experiments. Guided by a combination of lectures, seminar talks (based on original publications) and practical training, the participants will gain insight into recent developments in photonics/quantum optics.

Contents of the Course:
Will be given in the bulletin of lectures. The main theme will vary from term to term

Recommended Literature:
Will be given in the lecture

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: Lecture on Advanced Topics in Quantum Optics (E)

Course No.: physics738

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

Requirements for Participation:

Preparation:
Fundamentals of Quantum Mechanics, Atomic Physics

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

Length of Course:
1 semester

Aims of the Course:
The goal of the course is to introduce the students to a special field of research in quantum optics. New research results will be presented and their relevance is discussed.

Contents of the Course:
Will be given in the bulletin of lectures. The main theme will vary from term to term

Recommended Literature:
Will be given in the lecture

Modules:

physics70a **Elective Advanced Lectures: Experimental Physics**

physics70b **Elective Advanced Lectures: Applied Physics**

Course: Lecture on Advanced Topics in Photonics (E/A)

Course No.: physics739

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

Requirements for Participation:

Preparation:
Optics

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

Length of Course:
1 semester

Aims of the Course:
The goal of the course is to introduce the students to a special field of research in photonics. New research results will be presented and their relevance is discussed.

Contents of the Course:
Will be given in the bulletin of lectures. The main theme will vary from term to term

Recommended Literature:
Will be given in the lecture

This course may be offered as "Teaching hours (3+1)" with 6 cp, as well

Modules:

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

Course: Hands-on Seminar: Experimental Optics and Atomic Physics (E/A)

Course No.: physics740

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

Requirements for Participation:

Preparation:
Fundamentals of optics and quantum mechanics

Form of Testing and Examination:
Credit points can be obtained after successful carrying out the experiments and preparing a written report on selected experiments

Length of Course:
1 semester

Aims of the Course:
The students learn to handle optical setups and carry out optical experiments. This will prepare participants both for the successful completion of research projects in experimental quantum optics/photonics and tasks in the optics industry.

Contents of the Course:
Practical training in the field of optics, where the students start their experiment basically from scratch (i.e. an empty optical table). The training involves the following topics:
- diode lasers
- optical resonators
- acousto-optic modulators
- spectroscopy
- radiofrequency techniques

Recommended Literature:
Will be given by the supervisor

Modules:

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

Course: universitätbonn Modern Spectroscopy (E/A)

Course No.: physics741

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

Requirements for Participation:

Preparation:
Fundamentals of Optics, Fundamentals of Quantum Mechanics

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

Length of Course:
1 semester

Aims of the Course:
The aim of the course is to introduce the students to both fundamental and advanced concepts of spectroscopy and enable them to practically apply their knowledge.

Contents of the Course:
Spectroscopy phenomena - time and frequency domain;
high resolution spectroscopy;
pulsed spectroscopy; frequency combs;
coherent spectroscopy;
nonlinear spectroscopy: Saturation, Raman spectroscopy, Ramsey spectroscopy.
Applications of spectroscopic methods (e.g. Single molecule spectroscopy; spectroscopy at interfaces & surfaces, spectroscopy of cold atoms; atomic clocks; atom interferometry)

Recommended Literature:
W. Demtröder; Laser spectroscopy (Springer 2002)
S. Svanberg; Atomic and molecular spectroscopy basic aspects and practical applications (Springer 2001)
A. Corney; Atomic and laser spectroscopy (Clarendon Press 1988)
N. B. Colthup, L. H. Daly, S. E. Wiberley; Introduction to infrared and Raman spectroscopy (Academic Press 1990)
P. Hannaford; Femtosecond laser spectroscopy (Springer New York 2005)
C. Rulliere; Femtosecond laser pulses: principles and experiments (Springer Berlin 1998)

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)

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: Platforms for Quantum Technologies (E)

Course No.: physics743

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

Requirements for Participation:

Preparation:
Major courses of the 1st MSc term, for example, "Advanced Atomic, Molecular and Optical Physics", "Quantum Optics", "Advanced Quantum Theory", "Theoretical Condensed Matter Physics"

Form of Testing and Examination:
Homework Sheets

Length of Course:
1 week

Aims of the Course:
Students receive an introduction into quantum technologies both theoretically and experimentally. Focus is on the theoretical foundations of quantum information processing, and experimental platforms primarily used in Bonn (Atomic, molecular and optical systems), Cologne (topological materials) and Aachen (spin & superconducting architectures) in the context of the Excellence Cluster ML4Q.

Contents of the Course:
1. Basics of quantum information processing
2. Atomic, molecular and optical platforms, quantum simulation
3. Solid-state platforms. Focus on quantum computation. Spin qubits, superconducting qubits;
4. Topological platforms, Topological materials, Topological architectures

Recommended Literature:
Nielsen & Chuang "Quantum information processing"
Pethick/Smith "Bose-Einstein condensation"
Lecture notes will be distributed for selected topics

Module: Elective Advanced Lectures: Experimental Physics

Module No.: physics70a

Course: Precision Metrology (E)

Course No.: physics744

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

Requirements for Participation:

Preparation:
Fundamentals of Quantum Mechanics, Atomic Physics

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

Length of Course:
1 semester

Aims of the Course:
The aim of the course is to give the students a deeper insight to the field of precision metrology. Building on prior knowledge from the Bachelor courses it will cover topics from the field of sensing and metrology. The course will focus on work related to atomic physics and laser spectroscopy.

Contents of the Course:
Introduction to precision measurements: the system of SI units, systematic and statistical errors, precision and accuracy, error budgets, Allan deviation; the hydrogen atom and test of QED, including muonic hydrogen; atomic clocks: RF clocks, optical clocks (lattice clocks, ion clocks, nuclear clocks; matter wave interferometry; entanglement and squeezing; search for physics beyond the standard model in atomic physics: isotope shift spectroscopy, drifts in fundamental constants and dark matter, Lorentz violation, parity violation; ring laser gyroscopes for rotation sensing; technology: lasers, frequency combs, resonators. Possible topics outside of atomic physics include tests of special relativity and gravitational wave detection.

Recommended Literature:
Will be given in the lecture

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

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)

Module No.: physics70b
Credit Points (CP): 3-6
Category: Elective
Semester: 1.-2.

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Elective Advanced Lectures: Applied Physics

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Selected courses from catalogue type "A" (Applied) or "E/A" (Experimental/A)	see catalogue	3-6	see catalogue	90-180 hrs	ST/WT
2.	Also possible classes from M.Sc. in Astrophysics					

Requirements for Participation:
none

Form of Examination:
see with the course

Content:
Advanced lectures in applied 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**
physics70b **Elective Advanced Lectures: Applied Physics**

Course: Advanced Electronics and Signal Processing (E/A)

Course No.: physics712

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

Requirements for Participation:

Preparation:
Electronics laboratory of the B.Sc. in physics programme
Recommended: module nuclear and particle physics of the B.Sc. programme

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

Length of Course:
1 semester

Aims of the Course:
Comprehension of the basics of electronics circuits for the processing of (detector) signals, mediation of the basics of experimental techniques regarding electronics and micro electronics as well as signal processing

Contents of the Course:
The physics of electronic devices, junctions, transistors (BJT and FET), standard analog and digital circuits, amplifiers, elements of CMOS technologies, signal processing, ADC, DAC, noise sources and noise filtering, coupling of electronics to sensors/detectors, elements of chip design, VLSI electronics, readout techniques for detectors

Recommended Literature:
P. Horowitz, W. Hill; The Art of Electronics (Cambridge University Press 2. Aufl. 1989)
S. Sze; The Physics of Semiconductor Devices (Wiley & Sons 1981)
H. Spieler, Semiconductor detector system (Oxford University Press 2005))
J. Krenz; Electronics Concepts (Cambridge University Press 2000)

Modules:

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

Course: Particle Detectors and Instrumentation (E/A)

Course No.: physics713

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

Requirements for Participation:

Preparation:
Completed B.Sc. in Physics, with experience in quantum mechanics, atomic- and nuclear 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:
Designing an experiment in photoproduction on pi-0, selection and building of appropriate detectors, set-up and implementation of an experiment at ELSA

Contents of the Course:
Quark structure of mesons and baryons, nucleon excitation; electromagnetic probes, electron accelerators, photon beams, relativistic kinematics interaction of radiation with matter, detectors for photons, leptons and hadrons; laboratory course: setup of detectors and experiment at ELSA

Recommended Literature:
B. Povh, K. Rith, C. Scholz, F. Zetsche; Teilchen und Kerne (Springer, Heidelberg 6. Aufl. 2004)
Perkins; Introduction to High Energy Physics (Cambridge University Press 4. Aufl. 2000)
W. R. Leo; Techniques for Nuclear and Particle Detection (Springer, Heidelberg 2. Ed. 1994)
K. Kleinknecht; Detektoren für Teilchenstrahlung (Teubner, Wiesbaden 4. überarb. Aufl. 2005)

Modules:		
	physics70a	**Elective Advanced Lectures: Experimental Physics**
	physics70b	**Elective Advanced Lectures: Applied Physics**

Course: Advanced Accelerator Physics (E/A)

Course No.: physics714

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

Requirements for Participation:

Preparation:
Accelerator Physics (physics612)

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 of the physics of synchrotron radiation and its influence on beam parameters
Basic knowledge of collective phenomena in particle accelerators
General knowledge of applications of particle accelerators (research, medicine, energy management)

Contents of the Course:
Synchrotron radiation:
radiation power, spatial distribution, spectrum, damping, equilibrium beam emittance, beam lifetime
Space-charge effects:
self-field and wall effects, beam-beam effects, space charge dominated beam transport, neutralization of beams by ionization of the residual gas
Collective phenomena:
wake fields, wake functions and coupling impedances, spectra of a stationary and oscillating bunches, bunch interaction with an impedance, Robinson instability
Applications of particle accelerators:
medical accelerators, neutrino facilities, free electron lasers, nuclear waste transmutation, etc.

Recommended Literature:
F. Hinterberger; Physik der Teilchenbeschleuniger und Ionenoptik (Springer, Heidelberg 1997)
H. Wiedemann; Particle Accelerator Physics (Springer, Heidelberg 2 Aufl. 1999)
K. Wille; Physik der Teilchenbeschleuniger und Synchrotronstrahlungsquellen (Teubner, Wiesbaden 2. Aufl. 1996)
D. A. Edwards, M.J. Syphers; An Introduction to the Physics of High Energy Accelerators (Wiley & Sons 1993)
A. Chao; Physics of Collective Beam Instabilities in High Energy Accelerators (Wiley & Sons 1993)
Script of the Lecture Particle Accelerators (physics612)
http://www-elsa.physik.uni-bonn.de/~hillert/Beschleunigerphysik/

Modules:		
	physics70a	**Elective Advanced Lectures: Experimental Physics**
	physics70b	**Elective Advanced Lectures: Applied Physics**

Course: universitätbonn Scientific Programming with Python (E/A)

Course No.: physics725

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	6	ST

Requirements for Participation:

Preparation:
Prior knowledge of any programming language (C/C++, Java, Python, ...)

Form of Testing and Examination:
Successful implementation of scientific projects in Python during the semester

Length of Course:
1 semester

Aims of the Course:
Effective and flexible program solving with the easy-to-learn, high-level programming language Python. The course addresses master and PhD students with prior programming knowledge as taught in the bachelor course physics131.

Contents of the Course:
In-depth introduction to the Python programming language; Introduction to numpy arrays (primary Python data structure for scientific computing); Introduction to scientific-Python modules (scipy, astropy);
Interactive work / development with Python (ipython); Web interaction with Python (jupyter notebooks, web and database queries);
Plotting with Python (the matplotlib module), Introduction to writing own scientific Python-modules and Object-oriented programming, Collaborative code development and version control (git, github)

Recommended Literature:
All necessary materials are made available online via the eCampus platform

Credit points can only be earned from one exam out of physics718 and physics725

Modules:

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

Course: Programming in Physics and Astronomy with C++ or Python (E/A)

Course No.: physics718

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

Requirements for Participation:

Preparation:
Basic knowledge of programming and knowledge of simple C/C++ or Python constructs.

Form of Testing and Examination:
C/C++ part: Requirements for the examination (written or oral): successful work with the exercises.
Python part: Requirements for examination: successful implementation of the scientific projects in Python during the semester.

Length of Course:
1 semester

Aims of the Course:
C++ part: In-depth understanding of C++ and its applications in particle physics. Discussion of advanced features of C++ using examples from High Energy Physics. The course is intended for students with some background in C++ or for advanced students who wish to apply C++ in their graduate research.
Python part: Effective and flexible program solving with the easy-to-learn, high level programming language Python. The course addresses master and PhD students with prior Python-programming knowledge as taught in the bachelor course physics131.

Contents of the Course:
C++ part: - Basic ingredients of C++, - Object orientation: classes, inheritance, polymorphism, - How to solve physics problems with C++, - Standard Template Library, - C++ in data analysis, example: the ROOT library, - C++ and large scale calculations, - How to write and maintain complex programs, - Parallel computing and the Grid, - Debugging and profiling
Python part: - In-depth introduction to Python based on prior programming experience, - Introduction to numpy arrays (primary Python data structure for scientific computing), - Introduction to scientific-Python modules (scipy, astropy), - Interactive work / development with Python (ipython), - Web interaction with Python (jupyter notebooks, web and database queries), - Plotting with Python (the matplotlib module)

Recommended Literature:
Eckel: Thinking in C++, Prentice Hall 2000.
Lippman, Lajoie, Moo: C++ Primer, Addison-Wesley 2000.
Deitel and Deitel, C++ how to program, Prentice Hall 2007.
Stroustrup, The C++ Programming Language, Addison-Wesley 2000.

- The course is given in the summer term and alternates between C++ and Python
- The course can only be taken once for credit points.

Modules: physics70a **Elective Advanced Lectures: Experimental Physics**
physics70b **Elective Advanced Lectures: Applied Physics**

Course: Hands-on Seminar: Detector Construction (E/A)

Course No.: physics723

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

Requirements for Participation:
Basic knowledge of particle physics

Preparation:
physics618 is helpful but not mandatory

Form of Testing and Examination:
Credit points can be obtained after successful construction and operation of the detector and preparing a written and/or oral report on a specific task

Length of Course:
1 semester

Aims of the Course:
Students will design, construct, assemble and operate a particle detector.

Contents of the Course:
Students will construct, assemble and commission a particle detector. They will gain hands-on experience on detector construction. The students organize and execute the tasks of the project in personal responsibility. This includes many tasks common to more complex research or industrial projects. Topics include:

- order the needed detector components
- prepare CAD drawings
- prepare PCB layout
- develop electronic circuits
- produce and assemble detector parts
- vacuum technology
- cooling technology
- organize the work effort in personal responsibility
- communicate with team members and technical staff

Recommended Literature:
H. Kolanoski, N. Wermes, Teilchendetektoren, (Springer, Heidelberg, 2016)
W. R. Leo; Techniques for Nuclear and Particle Detection (Springer, Heidelberg 2. Ed. 1994)
K. Kleinknecht; Detektoren für Teilchenstrahlung (Teubner, Wiesbaden 4. überarb. Aufl. 2005)

Modules:

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

Course: universitätbonn Low Temperature Physics (E/A)

Course No.: physics731

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

Requirements for Participation:

Preparation:
Elementary thermodynamics; principles of quantum mechanics; introductory lecture on solid state 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:
Experimental methods at low (down to micro Kelvin) temperatures; methods of refrigeration; thermometry; solid state physics at low temperatures

Contents of the Course:
Thermodynamics of different refrigeration processes, liquefaction of gases; methods to reach low (< 1 Kelvin) temperatures: evaporation cooling, He-3-He-4 dilution cooling, Pomeranchuk effect, adiabatic demagnetisation of atoms and nuclei; thermometry at low temperatures (e.g. helium, magnetic thermometry, noise thermometry, thermometry using radioactive nuclei); principles for the construction of cryostats for low temperatures

Recommended Literature:
O.V. Lounasmaa; Experimental Principles and Methods Below 1K (Academic Press, London 1974)
R.C. Richardson, E.N. Smith; Experimental Techniques in Condensed Matter Physics at Low Temperatures (Addison-Wesley 1988)
F. Pobell, Matter and Methods at Low Temperatures (Springer-Verlag, Heidelberg 2. Aufl. 1996)

Modules:

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

Course: Optics Lab (E/A)

Course No.: physics732

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

Requirements for Participation:

Preparation:

Form of Testing and Examination:
Credit points can be obtained after completion of a written report.

Length of Course:
4-6 weeks

Aims of the Course:
The student learns to handle his/her own research project within one of the optics groups

Available projects and contact information can be found at: http://www.iap.uni-bonn.de/opticslab/

Contents of the Course:
Practical training/internship in a research group, which can have several aspects:
- setting up a small experiment
- testing and understanding the limits of experimental components
- simulating experimental situations

Recommended Literature:
Will be given by the supervisor

Modules:

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

Course: Holography (E/A)

Course No.: physics734

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

Requirements for Participation:

Preparation:

Form of Testing and Examination:
Written or oral examination

Length of Course:
1 semester

Aims of the Course:
The goal of the course is to provide in-depth knowledge and to provide practical abilities in the field of holography as an actual topic of applied optics

Contents of the Course:
The course will cover the basic principle of holography, holographic recording materials, and applications of holography. In the first part the idea behind holography will be explained and different hologram types will be discussed (transmission and reflection holograms; thin and thick holograms; amplitude and phase holograms; white-light holograms; computer-generated holograms; printed holograms). A key issue is the holographic recording material, and several material classes will be introduced in the course (photographic emulsions; photochromic materials; photo-polymerization; photo-addressable polymers; photorefractive crystals; photosensitive inorganic glasses). In the third section several fascinating applications of holography will be discussed (art; security-features on credit cards, banknotes, and passports; laser technology; data storage; image processing; filters and switches for optical telecommunication networks; novelty filters; phase conjugation ["time machine"]; femtosecond holography; space-time conversion). Interested students can also participate in practical training. An experimental setup to fabricate own holograms is available

Recommended Literature:
Lecture notes;
P. Hariharan; Optical Holography - Principles, Techniques, and Applications (Cambridge University Press, 2nd Edition, 1996)
P. Hariharan; Basics of Holography (Cambridge University Press 2002)
J. W. Goodman; Introduction to Fourier Optics (McGraw-Hill Education - Europe 2nd Ed. 2000)
A. Yariv; Photonics (Oxford University Press 6th Ed. 2006)

Modules:

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

Course: Crystal Optics (E/A)

Course No.: physics736

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

Requirements for Participation:

Preparation:

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:
Because of their aesthetic nature crystals are termed "flowers of mineral kingdom". The aesthetic aspect is closely related to the symmetry of the crystals which in turn determines their optical properties. It is the purpose of this course to stimulate the understanding of these relations. The mathematical and tools for describing symmetry and an introduction to polarization optics will be given before the optical properties following from crystal symmetry are discussed. Particular emphasis will be put on the magneto-optical properties of crystals in magnetic internal or external fields. Advanced topics such as the determination of magnetic structures and interactions by nonlinear magneto-optics will conclude the course

Contents of the Course:
Crystal classes and their symmetry; basic group theory; polarized light; optical properties in the absence of fields; electro-optical properties; magneto-optical properties: Faraday effect, Kerr effect, magneto-optical materials and devices, semiconductor magneto-optics, time-resolved magneto-optics, nonlinear magneto-optics

Recommended Literature:
R. R. Birss, Symmetry and Magnetism, North-Holland (1966)
R. E. Newnham: Properties of Materials: Anisotropy, Symmetry, Structure, Oxford University (2005)
A. K. Zvezdin, V. A. Kotov: Modern Magnetooptics & Magnetooptical Materials, Taylor/Francis (1997)
Y. R. Shen: The Principles of Nonlinear Optics, Wiley (2002)
K. H. Bennemann: Nonlinear Optics in Metals, Oxford University (1999)

Modules:

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

Course: Lecture on Advanced Topics in Photonics (E/A)

Course No.: physics739

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

Requirements for Participation:

Preparation:
Optics

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

Length of Course:
1 semester

Aims of the Course:
The goal of the course is to introduce the students to a special field of research in photonics. New research results will be presented and their relevance is discussed.

Contents of the Course:
Will be given in the bulletin of lectures. The main theme will vary from term to term

Recommended Literature:
Will be given in the lecture

This course may be offered as "Teaching hours (3+1)" with 6 cp, as well

Modules:		
	physics70a	**Elective Advanced Lectures: Experimental Physics**
	physics70b	**Elective Advanced Lectures: Applied Physics**

Course: Hands-on Seminar: Experimental Optics and Atomic Physics (E/A)

Course No.: physics740

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

Requirements for Participation:

Preparation:
Fundamentals of optics and quantum mechanics

Form of Testing and Examination:
Credit points can be obtained after successful carrying out the experiments and preparing a written report on selected experiments

Length of Course:
1 semester

Aims of the Course:
The students learn to handle optical setups and carry out optical experiments. This will prepare participants both for the successful completion of research projects in experimental quantum optics/photonics and tasks in the optics industry.

Contents of the Course:
Practical training in the field of optics, where the students start their experiment basically from scratch (i.e. an empty optical table). The training involves the following topics:
- diode lasers
- optical resonators
- acousto-optic modulators
- spectroscopy
- radiofrequency techniques

Recommended Literature:
Will be given by the supervisor

Modules:

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

Course: Modern Spectroscopy (E/A)

Course No.: physics741

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

Requirements for Participation:

Preparation:
Fundamentals of Optics, Fundamentals of Quantum Mechanics

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

Length of Course:
1 semester

Aims of the Course:
The aim of the course is to introduce the students to both fundamental and advanced concepts of spectroscopy and enable them to practically apply their knowledge.

Contents of the Course:
Spectroscopy phenomena - time and frequency domain;
high resolution spectroscopy;
pulsed spectroscopy; frequency combs;
coherent spectroscopy;
nonlinear spectroscopy: Saturation, Raman spectroscopy, Ramsey spectroscopy.
Applications of spectroscopic methods (e.g. Single molecule spectroscopy; spectroscopy at interfaces & surfaces, spectroscopy of cold atoms; atomic clocks; atom interferometry)

Recommended Literature:
W. Demtröder; Laser spectroscopy (Springer 2002)
S. Svanberg; Atomic and molecular spectroscopy basic aspects and practical applications (Springer 2001)
A. Corney; Atomic and laser spectroscopy (Clarendon Press 1988)
N. B. Colthup, L. H. Daly, S. E. Wiberley; Introduction to infrared and Raman spectroscopy (Academic Press 1990)
P. Hannaford; Femtosecond laser spectroscopy (Springer New York 2005)
C. Rulliere; Femtosecond laser pulses: principles and experiments (Springer Berlin 1998)

Module: Elective Advanced Lectures: Applied Physics

Module No.: physics70b

Course: Environmental Physics & Energy Physics (A)

Course No.: physics771

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

Requirements for Participation:

Preparation:
Physik I-V (physik110-physik510)

Form of Testing and Examination:
Active contributions during term and written examination

Length of Course:
1 semester

Aims of the Course:
A deeper understanding of energy & environmental facts and problems from physics (and, if needed, nature or agricultural science) point of view

Contents of the Course:
After introduction into related laws of nature and after a review of supply and use of various resources like energy a detailed description on each field of use, use-improvement strategies and constraints and consequences for environment and/or human health & welfare are given.

Recommended Literature:
Diekmann, B., Heinloth, K.: Physikalische Grundlagen der Energieerzeugung, Teubner 1997
Hensing, I., Pfaffenberger, W., Ströbele, W.: Energiewirtschaft, Oldenbourg1998
Fricke, J., Borst, W., Energie, Oldenbourg 1986
Bobin, J. L.,Huffer,E., Nifenecker,H., L'Energie de Demain ,EDP Sciences 2005
Thorndyke, W., Energy and Environment, Addison Wesley 1976
Schönwiese, C. D., Diekmann, B., Der Treibhauseffekt , DVA 1986
Boeker, E., von Grondelle, R., Physik und Umwelt, Vieweg, 1997

Module: Elective Advanced Lectures: Applied Physics

Module No.: physics70b

Course: Physics in Medicine: Fundamentals of Analyzing Biomedical Signals (A)

Course No.: physics772

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

Requirements for Participation:

Preparation:
Elementary thermodynamics; principles of quantum mechanics, principles of condensed matter

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 of the principles of physics and the analysis of complex systems

Contents of the Course:
Introduction to the theory of nonlinear dynamical systems; selected phenomena (e.g. noise-induced transition, stochastic resonance, self-organized criticality); Nonlinear time series analysis: state-space reconstruction, dimensions, Lyapunov exponents, entropies, determinism, synchronization, interdependencies, surrogate concepts, measuring non-stationarity.
Applications: nonlinear analysis of biomedical time series (EEG, MEG, EKG)

Recommended Literature:
Lehnertz: Skriptum zur Vorlesung
E. Ott; Chaos in dynamical systems (Cambridge University Press 2. Aufl. 2002)
H. Kantz, T. Schreiber ; Nonlinear time series analysis. (Cambridge University Press 2:Aufl. 2004).
A. Pikovsky, M. Rosenblum, J. Kurths; Synchronization: a universal concept in nonlinear sciences (Cambridge University Press 2003)

Module: Elective Advanced Lectures: Applied Physics

Module No.: physics70b

Course: Physics in Medicine: Fundamentals of Medical Imaging (A)

Course No.: physics773

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

Requirements for Participation:

Preparation:
Lectures Experimental Physics I-III (physik111-physik311) respectively

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 of the principles of physics of modern imaging techniques in medicine

Contents of the Course:
Introduction to physical imaging methods and medical imaging; Physical fundamentals of transmission computer tomography (Röntgen-CT), positron emission computer tomography (PET), magnetic resonance imaging (MRI) and functional MRI
detectors, instrumentation, data acquisition, tracer, image reconstruction, BOLD effect; applications: analysis of structure and function.
Neuromagnetic (MEG) and Neuroelectrical (EEG) Imaging; Basics of neuroelectromagnetic activity, source models
instrumentation, detectors, SQUIDs; signal analysis, source imaging, inverse problems, applications

Recommended Literature:
K. Lehnertz: Scriptum zur Vorlesung
S. Webb; The Physics of Medical Imaging (Adam Hilger, Bristol 1988)
O. Dössel; Bildgebende Verfahren in der Medizin (Springer, Heidelberg 2000)
W. Buckel; Supraleitung (Wiley-VCH Weinheim 6. Aufl. 2004)
E. Niedermeyer/F. H. Lopes da Silva; Electroencephalography (Urban & Schwarzenberg, 1982)

Module: Elective Advanced Lectures: Applied Physics

Module No.: physics70b

Course: Electronics for Physicists (E/A)

Course No.: physics774

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

Requirements for Participation:

Preparation:
Electronics laboratory of the B.Sc. in physics programme

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

Length of Course:
1 semester

Aims of the Course:
Comprehension of electronic components, methods to derive the dynamical performance of circuits and mediation that these methods are widely used in various fields of physics

Contents of the Course:
Basics of electrical engineering, RF-electronics I: Telegraph equation, impedance matching for lumped circuits and electromagnetic fields, diodes, transistors, analogue and digital integrated circuits, system analysis via laplace transformation, basic circuits, circuit synthesis, closed loop circuits, oscillators, filters, RF-electronics II: low-noise oscillators and amplifiers

Recommended Literature:
P. Horrowitz, W. Hill; The Art of Electronics (Cambridge University Press)
Murray R. Spiegel; Laplace Transformation (McGraw-Hill Book Company)
A.J. Baden Fuller; Mikrowellen (Vieweg)
Lutz v. Wangenheim; Aktive Filter (Hüthig)

Module: Elective Advanced Lectures: Applied Physics

Module No.: physics70b

Course: Nuclear Reactor Physics (A)

Course No.: physics775

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

Requirements for Participation:

Preparation:
Fundamental nuclear physics

Form of Testing and Examination:
Written or oral examination

Length of Course:
1 semester

Aims of the Course:
Deeper understanding of nuclear power generation (fisson and fusion)

Contents of the Course:
Physics of nuclear fission and fusion, neutron flux in reactors, different reactor types, safety aspects, nuclear waste problem, future aspects
and
Excursion to a nuclear power plant

Recommended Literature:
H. Hübel: Reaktorphysik (Vorlesungsskript, available during the lecture)
M. Borlein: Kerntechnik, Vogel (2009)
W. M. Stacey: Nuclear Reactor Physics, Wiley & Sons (2007)

Module: Elective Advanced Lectures: Applied Physics

Module No.: physics70b

Course: Physics in Medicine: Physics of Magnetic Resonance Imaging (A)

Course No.: physics776

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

Requirements for Participation:

Preparation:
Lectures Experimental Physics I-III (physik111-physik311) respectively

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 the principles of Magnetic Resonance Imaging Physics

Contents of the Course:
- Theory and origin of nuclear magnetic resonance (QM and semiclassical approach)
- Spin dynamics, T1 and T2 relaxation, Bloch Equations and the Signal Equation
- Gradient echoes and spin echoes and the difference between T2 and T2*
- On- and off-resonant excitation and the slice selection process
- Spatial encoding by means of gradient fields and the k-space formalism
- Basic imaging sequences and their basic contrasts, basic imaging artifacts
- Hardware components of an MRI scanner, accelerated imaging with multiple receiver
- Computation of signal amplitudes in steady state sequences
- The ultra-fast imaging sequence EPI and its application in functional MRI
- Basics theory of diffusion MRI and its application in neuroimaging
- Advanced topics: quantitative MRI, spectroscopic imaging, X-nuclei MRI

Recommended Literature:
- T. Stöcker: Scriptum zur Vorlesung
- E.M. Haacke et al, Magnetic Resonance Imaging: Physical Principles and Sequence Design, John Wiley 1999
- M.T. Vlaardingerbroek, J.A. den Boer, Magnetic Resonance Imaging: Theory and Practice, Springer, 20
- Z.P. Liang, P.C. Lauterbur, Principles of Magnetic Resonance Imaging: A Signal Processing Perspective, SPIE 1999

Module: Elective Advanced Lectures: Applied Physics

Module No.: physics70b

Course: Physics in Medicine: Cardiovascular Magnetic Resonance Imaging (CMRI) (A)

Course No.: physics777

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

Requirements for Participation:

Preparation:
Lectures Experimental Physics I-III (physik111-physik311) respectively

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 the principles of physics of Cardiovascular Magnetic Resonance Imaging (CMRI)

Contents of the Course:
1. Basic principles of MRI I (Bloch equation, spatial encoding)
2. Basic principles of MRI II (extended Bloch equation)
3. k-space trajectories and reconstruction techniques (Cartesian data: Fast Fourier transform (FFT); Non Cartesian: Nonuniform fast Fourier transform (NUFFT), REGRIDDING, BACK PROJECTION)
4. Basic principles of CMRI (physiology, motion correction, gating strategies)
5. Preclinical MRI systems at high magnetic fields (7T and above) – hardware, advantages and limitations

6. Magnetic resonance contrast agents (from a biophysical point of view, hands-on at MRI)
7. Myocardial relaxometry (T1, T2, T2* mapping, Extracellular Volume mapping, hands-on at MRI)
8. Magnetic resonance angiography (contrast enhanced MR angiography, navigator-based MR angiography)
9. CMRI of moving spins (blood flow velocity: phase contrast MRI, 4D velocity vector fields, velocity-time curves, vorticity, helicity, streamlining, pathfinding, hands-on at MRI)
10. Myocardial perfusion imaging (contrast-enhanced imaging techniques, Arterial Spin Labeling)
11. Myocardial architecture imaging (Diffusion-weighted magnetic resonance imaging (DWI), Diffusion tensor imaging (DTI), quantitative analysis, hands-on at MRI)
12. Myocardial MR Spectroscopy (Point Resolved Spectroscopy (PRESS), Stimulated Echo Acquisition Mode (STEAM), Chemical Shift Imaging (CSI), 31P-Image-Selected In vivo Spectroscopy (ISIS))
13. Novel approaches in metabolic MRI of the heart (Chemical exchange saturation transfer (CEST), Magnetization transfer contrast (MTC), comparison to 1H-MR Spectroscopy, quantitative analysis)
14. Concepts of acceleration in cardiac MRI at preclinical systems (Compressed Sensing (CS), Total Variation (TV), Parallel Imaging)

Recommended Literature:
1. V. Hörr: Scriptum zur Vorlesung

2. MRI: The Basics, Ray H. Hashemi, William G. Bradley, Christopher J. Lisanti, Lippincott Williams & Wilkins.
3. In Vivo NMR Spectroscopy, Robin de Graaf, John Wiley & Sons.
4. Compressed Sensing Magnetic Resonance Image Reconstruction Algorithms, Bhabesh Deka, Sumit Datta, Springer.
5. Magnetic Resonance Imaging: Physical Principles and Sequence Design, Robert W. Brown, Yu-Chung N. Cheng, E. Mark Haacke, Michael R. Thompson, Ramesh Venkatesan, John Wiley & Sons.
6. Cardiovascular Magnetic Resonance, Warren J. Manning, Dudley J. Pennell, Elsevier.

Module: Elective Advanced Lectures: Applied Physics

Module No.: physics70b

Course: "Energy Production" (A)

Course No.: physics778

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

Requirements for Participation:

Preparation:
Physik I-V (physik110-physik510)

Form of Testing and Examination:
Written or oral examination

Length of Course:
1 semester

Aims of the Course:
The course intends to provide an overview in the field of today's challenges in "energy production" from a physics point of view.

Contents of the Course:
Energy storage & transport

Nuclear power
- Solar (photovoltaics, thermal, wind, water)
- Geothermal
- Reactors (fission / fusion)

Moon power (tidal power plants)

Recommended Literature:
Will be given during the course

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

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)

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: universitätbonn 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: 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: 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: 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: universitätbonn 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)

universitätbonn

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)

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).

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Time Evolution of Quantum Systems (T)

Course No.: physics7518

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, solid knowledge of a programming language

Form of Testing and Examination:
Presentation of an independently completed project

Length of Course:
1 semester

Aims of the Course:
Getting familiar with common problems arising in the time evolution of quantum systems and approaches to solve them

Contents of the Course:
A selection of:
- Real time evolution
- Imaginary time evolution
- Analytic continuation
- Approximation methods
- Numerical solution of stiff equations of motion
- Floquet theory
- Open quantum systems
- Non-equilibrium dynamics

Recommended Literature:
- W. H. Press, S. A. Teukolsky, W. T. Vetterling, B. P. Flannery, "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press.
- E. Hairer, G. Wanner, "Solving Ordinary Differential Equations II: Stiff and Differential-Algebraic Problems", Springer.
- Research and review articles tba in the lecture.

Module: Elective Advanced Lectures: Theoretical Physics

Module No.: physics70c

Course: Surprises in Quantum Mechanics (T)

Course No.: physics7519

Category	Type	Language	Teaching hours	CP	Semester
Elective	Mixed lecture and seminar	English	2	4	WT/ST

Requirements for Participation:

Preparation:
Advanced Quantum Theory (physics606)

Form of Testing and Examination:
Presentation of an independently completed project

Length of Course:
1 semester

Aims of the Course:
Gaining a deeper understanding of quantum mechanics, including several so-called paradoxa, covering both theoretical and experimental aspects

Contents of the Course:
Basic formalism of quantum mechanics, followed by a selection of:
Pitfalls in infinitely dimensional Hilbert spaces
Classical vs quantum mechanical correlations
When does interference occur, when is it destroyed?
The "quantum eraser"
Quantum mechanical description of measurement devices
A quantum measurement yielding S_z = 42 for a spin-1/2 particle
How to ascertain all spin components of a spin-1/2 particle ("quantum card trick")
Quantum mechanics without "collapse of the wave function"?
Generalizations of the Aharonov-Bohm effect
Hanbury-Brown-Twiss correlations

Recommended Literature:
Mostly research and review articles will be used. Some of the topics are discussed in
Y. Aharonov, D. Rohrlich, "Quantum paradoxes: quantum theory for the perplexed", Wiley, 2005

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

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)

Module No.: physics70d
Credit Points (CP): 3-8
Category: Elective
Semester: 1.-2.

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Elective Advanced Lectures: BCGS Courses

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Selected courses from catalogue	see catalogue	3-8	see catalogue	90-240 hrs	WT/ST

Requirements for Participation:
none

Form of Examination:
see with the course

Content:
Advanced lectures within the Bonn Cologne Graduate School of Physics and Astronomy (BCGS).

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

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Relativity and Cosmology I (T)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	4+2	8	WT

Requirements for Participation:

Preparation:
Training in theoretical physics at the B.Sc. level

Form of Testing and Examination:
Written or oral examination

Length of Course:
1 semester

Aims of the Course:
Introduction into Einstein's theory of general relativity and its major applications

Contents of the Course:
Gravity as a manifestation of geometry
Introduction to differential geometry
Einstein field equations
The Schwarzschild solution
Experimental tests
Gravitational waves

Recommended Literature:
T. Padmanabhan, Gravitation: Foundation and Frontiers
J. B. Hartle, Gravity: An introduction to Einstein's general relativity

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Relativity and Cosmology II (T)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	4+2	8	ST

Requirements for Participation:

Preparation:
Training in theoretical physics at the B.Sc. level

Form of Testing and Examination:
Written or oral examination

Length of Course:
1 semester

Aims of the Course:
Application of Einstein's theory of general relativity to black holes and cosmology

Contents of the Course:
Black holes
Introduction to cosmology
The early Universe

Recommended Literature:
V. Mukhanov, Physical Foundations of Cosmology
T. Padmanabhan, Gravitation: Foundation and Frontiers
J. B. Hartle, Gravity: An introduction to Einstein's general relativity

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Quantum Field Theory I (T)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	4+2	8	ST

Requirements for Participation:

Preparation:
Training in theoretical physics at the B.Sc. level

Form of Testing and Examination:
Written or oral examination

Length of Course:
1 semester

Aims of the Course:
Methods of quantum field theory are in use in almost all areas of modern physics. Strongly oriented towards applications, this course offers an introduction based on examples and phenomena taken from the area of solid state physics.

Contents of the Course:
Second quantization and applications
Functional integrals
Perturbation theory
Mean-field methods

Recommended Literature:
A. Altland and B.D. Simons, Condensed Matter Field Theory (Cambridge University Press, Cambridge, second edition: 2010)

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Quantum Field Theory II (T)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	4+2	8	ST

Requirements for Participation:

Preparation:
Quantum Field Theory I

Form of Testing and Examination:
Written or oral examination

Length of Course:
1 semester

Aims of the Course:
Quantum field theory is one of the main tools of modern physics with many applications ranging from high-energy physics to solid state physics. A central topic of this course is the concept of spontaneous symmetry breaking and its relevance for phenomena like superconductivity, magnetism or mass generation in particle physics.

Contents of the Course:
Correlation functions: formalism, and their role as a bridge between theory and experiment
Renormalization
Topological concepts

Recommended Literature:
A. Altland and B.D. Simons, Condensed Matter Field Theory (Cambridge University Press, Cambridge, second edition: 2010)

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Geometry in Physics (T)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	4+2	8	ST

Requirements for Participation:

Preparation:
Training in theoretical physics at the B.Sc. level

Form of Testing and Examination:
Written or oral examination

Length of Course:
1 semester

Aims of the Course:
The course introduces the background in differential geometry necessary to understand the geometrically oriented languages of modern theoretical physics. Applications include the coordinate invariant formulation of electrodynamics, phase space and symplectic mechanics, and a brief introduction to the foundations of general relativity.

Contents of the Course:
exterior calculus
manifolds
Lie groups
fibre bundles

Recommended Literature:
M. Göckeler & T. Schücker, Differential geometry, gauge theory, and gravity, Cambridge University Press, 1987.

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Topology for Physicists (T)

Course No.:

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

Requirements for Participation:

Preparation:
Bachelor of physics or mathematics; the basics of exterior calculus are assumed

Form of Testing and Examination:
Written or oral examination

Length of Course:
1 semester

Aims of the Course:
This course gives an introduction to various topological concepts and results that play an important role in modern theoretical physics.

Contents of the Course:
Elements of homotopy theory: homeomorphic spaces, homotopic maps, fundamental group, covering spaces, homotopy groups, long exact homotopy sequence of a fibration
Homology and cohomology: Poincare lemma, Mayer-Vietoris sequence, Cech-deRham complex, Hurewicz isomorphism theorem, spectral sequences
Vector bundles and characteristic classes: Euler form, Thom isomorphism, Chern classes
Applications: Berry phase; Dirac monopole problem; visualization of closed differential forms by Poincare duality; cohomology of electrical conductance; supersymmetry and Morse theory; index theorems; homotopy classification of topological insulators

Recommended Literature:
R. Bott and L.W. Tu: Differential forms in algebraic topology (Springer, 1982)
A.S. Schwarz, Topology for physicists (Springer, 1994)

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Nuclear physics II (E)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	3	5	WT

Requirements for Participation:

Preparation:
Nuclear Physics I, Quantum Mechanics

Form of Testing and Examination:
Part of the obligatory courses for area of specialisation Nuclear and Particle Physics, separate oral examination is possible exceptionally.

Length of Course:
1 semester

Aims of the Course:
Study of nuclear reactions, fission and fusion.

Contents of the Course:
- Kinematics in nuclear reactions
- Cross section
- Rutherford scattering
- Scattering in quantum mechanics
- The Born approximation
- Partial wave analysis
- Inelastic scattering, resonances
- Optical model
- Direct, compound, spallation and fragmentation reactions
- Neutron sources and detectors
- Neutron cross sections
- Fission
- Nuclear reactors
- Fusion
- Solar fusion
- Man-made thermonuclear fusion
- Controlled thermonuclear fusion

Recommended Literature:
A script for parts of the course will be distributed during the course.
K.S. Krane, Introductory nuclear physics, chapters 11-14

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Physics of Detectors (E/A)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	3	4	ST

Requirements for Participation:

Preparation:
Nuclear Physics I, Quantum Mechanics

Form of Testing and Examination:
Part of the obligatory courses for area of specialisation Nuclear and Particle Physics, separate oral examination is possible exceptionally.

Length of Course:
1 semester

Aims of the Course:
Study detection methods of experimental techniques in nuclear and particle physics.

Contents of the Course:
- Interaction of electrons and charged heavy particles in matter
- Coherent effects: Cherenkov and transition radiation
- Interaction of gamma-radiation in matter
- Detection of neutal particles: neutrons and neutrinos
- Measurement of 4-momentum in particle physics
- Ionisation detectors: Bragg chamber, avalanche detectors
- Position sensitive detectors: drift chambers, time-procjection chamber
- Anorganic and organic scintillators
- Energy detection, calorimeter and shower detectors
- Semiconductor detectors
- Position sensitive Si detectors (strip-, pixel-detectors)
- Ge detectors
- Low background measurements
- Lifetime measurements
- Mössbauer Spectroscopy
- Basic principles of analoge and digital signal processing

Recommended Literature:
A script or slides of the course will be distributed during the course.
R. Leo, Techniques for Nuclear and Particle Physics Experiments
K Kleinknecht, Detektoren für Teilchenstrahlung
G.F. Knoll, Radiation Detection and Measurement

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Particle physics (E)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	3	4	ST

Requirements for Participation:

Preparation:
Quantum Mechanics

Form of Testing and Examination:
Part of the obligatory courses for area of specialisation Nuclear and Particle Physics, separate oral examination is possible exceptionally.

Length of Course:
1 semester

Aims of the Course:
Introduction into particle physics, accelerators and detectors

Contents of the Course:
- Relativistic kinematics
- Interaction of radiation with matter
- Particle accelerators
- Targets and detectors
- Symmetries in particle physics
- QED
- Weak interaction, neutrinos
- Quark model
- QCD
- Standard model
- Cosmology

Recommended Literature:
A script for course will be available on-line

D.H. Perkins: Introduction to High Energy Physics, Cambridge University Press, ISBN 0521621968
H. Frauenfelder, E.M. Henley: Subatomic Physics, Prentice Hall, ISBN 0138594309
F. Halzen: A.D. Martin: Quarks and Leptons, John Wiley and Sons, ISBN 0471887412
D. Griffiths: Introduction to Elementary Particles, John Wiley and Sons ISBN: 0471603864
B. Povh, K. Rith, C. Scholz, F. Zetsche: Teilchen und Kerne, Springer-Verlag, ISBN 3540659285
C. Berger: Elementarteilchenphysik, Springer-Verlag, ISBN 3-540-41515-7

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Groundbreaking experiments in nuclear physics (E)

Course No.:

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

Requirements for Participation:

Preparation:
Basic knowledge in Nuclear Physics

Form of Testing and Examination:
Part of courses for area of specialisation Nuclear and Particle Physics, separate oral examination is possible exceptionally.

Length of Course:
1 semester

Aims of the Course:
Study of original publications of fundamental experiments in nuclear physics. The students should participate actively in the course.

Contents of the Course:
- Discovery of radioactivity
- Rutherford and his many discoveries using alpha sources
- The discovery of the neutron and deuteron
- Determination of magnetic moments
- Hofstadters electron scattering experiments
- The use of cosmic rays to discover mesons
- Fermi work in neutron physics
- Properties of neutrinos
- Mößbauereffekt

Recommended Literature:
Will be distributed during the course.

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Condensed Matter Physics II (E)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	3	4	ST

Requirements for Participation:

Preparation:
Basic knowledge in condensed matter physics and quantum mechanics

Form of Testing and Examination:
Oral examination

Length of Course:
2 semesters

Aims of the Course:
Advanced topics in condensed matter physics with examples of current research.

Contents of the Course:
The entire course (Condensed Matter I & II, given in 2 semesters) covers the following topics:
Crystal structure and binding
Reciprocal space
Lattice dynamics and thermal properties
Electronic structure (free-electron gas, Fermi surface, band structure)
Semiconductors and metals
Transport properties
Dielectric function and screening
Superconductivity
Magnetism

Recommended Literature:
Skriptum (available during the course)
Ashcroft/Mermin: Solid State Physics
Kittel: Introduction to Solid State Physics
Ibach/Lüth: Festkörperphysik

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Semiconductor Physics and Nanoscience (E/A)

Course No.:

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

Requirements for Participation:

Preparation:
Basic knowledge in condensed matter physics

Form of Testing and Examination:
No examination

Length of Course:
1 semester

Aims of the Course:
Understanding of theoretical and experimental concepts of semiconductor physics, nanotechnology as well as aspects of future information technology.
Knowledge of basic fields and important applications of information technology.

Contents of the Course:
Semiconducting material and nanostructures represent the backbone of modern electronics and information technology. At the same time they are fundamental to the research of problems of modern solid state physics, information technology and biophysics. This lecture will provide an introduction to semiconductor physics and its applications.
Topics covered are
introduction to semiconductor physics, crystalline structure, band structure, electronic and optical properties,
heterostructures, junction and interfaces,
basic semiconductor device concepts,
up to date techniques and strategies of information technology ranging from nowadays preparation technologies and nanoscience to concepts of molecular electronic and bioelectronics.

Recommended Literature:
Skriptum (available during the course)
Bergmann/Schäfer, Experimentalphysik (Band 6: Festkörper)
Ibach/Lüth, Festkörperphysik

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Superconductivity (E/A)

Course No.:

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

Requirements for Participation:

Preparation:
Basic knowledge in condensed matter physics

Form of Testing and Examination:
Oral examination

Length of Course:
1 semester

Aims of the Course:
Understanding of the fundamental aspects of superconductivity.

Contents of the Course:
The lecture provides an overview of the fundamental aspects of superconductivity, theoretical description and technological applications, including the following topics:

Basic experimental facts and critical parameters
Phenomenological description: London equations
Ginzburg-Landau theory
Magnetic flux quantization
Type I and type II superconductors, characteristic length scales, vortices
Microscopic description: BSC theory
Electron-phonon interaction, Cooper pairs
Josephson effects
Applications of superconductivity in science, transport, and medicine
Brief introduction to unconventional superconductivity with recent examples

Recommended Literature:
J. F. Annett: Superconductivity, Superfluids and Condensates (2004)
M. Tinkham: Introduction to Superconductivity (1996)
V. V. Schmidt: The Physics of Superconductors (1997)
J. R. Waldram: Superconductivity of Metals and Cuprates (1996)
D. R. Tilley and J. Tilley: Superfluidity and Superconductivity (1990)

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Magnetism (E/A)

Course No.:

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

Requirements for Participation:

Preparation:
Basic knowledge in condensed matter physics

Form of Testing and Examination:
Oral examination

Length of Course:
1 semester

Aims of the Course:
Understanding of magnetism in condensed matter systems

Contents of the Course:
The lecture introduces to the magnetism in condensed matter systems. Starting from basic concepts of the magnetic properties of free atoms it is aimed to illustrate the extremely rich field of collective magnetism that arises from the mutual interaction of an extremely large number of interacting particles.
Topics covered are
Magnetism of free atoms
Magnetism of ions in the crystal electric field
Magnetic interactions and ordering phenomena
Magnetic ground states and excitations
Itinerant magnetism
Magnetic frustration and low dimensionality
Magnetic order vs. competing ordering phenomena

Recommended Literature:
Skriptum (available during the course)
S. Blundell, Magnetism in Condensed Matter
Ashcroft/Mermin, Solid State Physics
Kittel, Festkörperphysik

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Experimental methods in condensed matter physics (E/A)

Course No.:

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

Requirements for Participation:

Preparation:
Basic knowledge in condensed matter physics

Form of Testing and Examination:
Oral examination

Length of Course:
1 semester

Aims of the Course:
Understanding of experimental concepts in condensed matter science
Knowledge of basic fields and important applications

Contents of the Course:
The lecture introduces to modern experimental approaches in solid state physics. Basic concepts are illustrated with examples of physical problems investigated employing different methods.
Topics covered are
Introduction on sample preparation
X-ray powder diffraction
Specific heat, Thermal expansion
Magnetization and magnetic susceptibility
DC-Transport
Dielectric spectroscopy
Photo-emission spectroscopy
Inelastic scattering (neutrons, light)
THz spectroscopy / Optical spectroscopy
Scanning probe microscopy/spectroscopy (AFM, STM)

Recommended Literature:
Skriptum (available during the course)
Bergmann/Schäfer, Experimentalphysik (Band 6: Festkörper)
Ibach/Lüth, Festkörperphysik
Ashcroft/Mermin, solid state physics

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Physics of Surfaces and Nanostructures (E/A)

Course No.:

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

Requirements for Participation:

Preparation:
Basic knowledge of solid state physics

Form of Testing and Examination:
Oral examination

Length of Course:
1 semester

Aims of the Course:
Understanding of fundamental concepts in surface and nanostructure science
Knowledge of basic fields and important applications

Contents of the Course:
The lecture introduces to modern topics of surface and nanostructure physics. Basic concepts are illustrated with examples and the link to technical applications is emphazised. Topics covered are
- surface structure and defects,
- adsorption and heterogeneous catalysis,
- surface thermodynamics and energetics
- surface electronic structure and quantum dots,
- magnetism at surfaces
- epitaxy and thin film processes,
- oxide films
- ion beam processes at surfaces,
- clusters,
- graphene

Recommended Literature:
Michely: Skriptum (available during the course)
H. Ibach: Physics of Surfaces and Interfaces (Springer, Berlin 2006)
K. Oura et al: Surface Science - an introduction (Springer, Berlin 2003)
M. Prutton: Introduction to Surface Physics (Oxford University Press, 1994)
H. Lüth: Solid Surfaces, Interfaces and Thin Films, (Springer, Berlin 2001)
M. Henzler/ W. Göpel: Oberflächenphysik des Festkörpers (Teubner, Stuttgart 1994)

Module:	**Elective Advanced Lectures: BCGS Courses**
Module No.: physics70d	

Course: Introduction to neutron scattering (E/A)

Course No.:

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

Requirements for Participation:

Preparation:
Basic knowledge in condensed matter physics

Form of Testing and Examination:
Oral examination

Length of Course:
1 semester

Aims of the Course:
Understanding of the basic concepts and techniques of elastic and inelastic neutron scattering experiments.

Contents of the Course:
The lecture introduces to the techniques of elastic and inelastic neutron scattering that can be used to determine the crystal or magnetic structure as well as the dispersion of nuclear or magnetic excitations.
Topics covered are
Crystal structures and reciprocal space
Neutron powder diffraction
Single-crystal diffraction
Structure refinements
Inelastic neutron scattering
Phonon dispersion
Magnetic excitations
Examples of current research (high-temperature superconductors, manganates with colossal magnetoresistivity, multiferroics)
Polarized neutron scattering

Recommended Literature:
Skriptum (available during the course)
S. W. Lovesey, Theory of Neutron Scattering from Condensed Matter, Oxford (1981)
G. E. Bacon, Neutron Diffraction, Oxford (1979)
Shirane, Shapiro and, Tranquada, Neutr. Scattering with a triple-axis spectrometer, Cambridge (2002)
Izyumov, Ozerov, Magnetic Neutron Diffraction Plenum (1970)
Marshall and Lovesey, Theory of thermal neutron scattering,Oxford (1971)
Squires, Introduction to the theory of Thermal Neutron scattering, Cambridge (1978)

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Optical Spectroscopy (E/A)

Course No.:

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

Requirements for Participation:

Preparation:
Basic knowledge in condensed matter physics

Form of Testing and Examination:
Oral examination

Length of Course:
1 semester

Aims of the Course:
Understanding of the basic concepts and techniques of optical spectroscopy on solid-state samples.

Contents of the Course:
Topics covered are:
Electromagnetic waves in matter, dielectric function
Electromagnetic response of metals and insulators, Drude-Lorentz model
Kramers-Kronig relations
THz spectroscopy (time domain and cw)
Fourier-transform spectroscopy
Ellipsometry
Examples of current research (phonons, magnons, orbital excitations, superconductors, …)

Recommended Literature:
Skriptum (available during the course)
Dressel/Grüner: Electrodynamics of Solids: Optical Properties of Electrons in Matter (Cambridge, 2002)
Klingshirn: Semiconductor Optics (Springer, 1997)
Kuzmany: Solid-State Spectroscopy: An Introduction (Springer, 2009)

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Astrochemistry (E/A)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	2	4	ST

Requirements for Participation:

Preparation:
Atomic Physics, Molecular Physics and Quantum Mechanics at the level of the bachelor courses in physics, Molecular Physics I

Form of Testing and Examination:
Oral Examination

Length of Course:
1 semester

Aims of the Course:
The lecture introduces to astrochemistry of various astrophysical environments. Fundamental processes, such as molecular collisions, fragmentations, and chemical reactions, are explained, and implications for astrophysical observations by means of high resolution spectroscopy are treated.

Contents of the Course:
- Detection of Molecules in Space
- Elementary Chemical Processes
- Chemical Networks
- Grain Formation (Condensation)
- Properties of Grains and Ice
- Grain Chemistry
- Diffuse Clouds, Shocks, Dark Clouds, Star Forming Regions

Recommended Literature:
A.Tielens "The Physics and Chemistry of the Interstellar Medium" Cambridge University Press, 2005
S. Kwok "Physics and Chemistry of the Interstellar Medium" University Science Books, 2006
D. Rehder "Chemistry in Space, From Interstellar Matter to the Origin of Life" Wiley-VCCH, Weinheim, 2010
J. Lequeux "The interstellar Medium" Spinger, 2004
A. Shaw "Astrochemistry" Wiley, 2006
D. Whittet "Dust in the Galactic Environment", Taylor and Francis, 2nd edition, 2002

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Fundamentals of Molecular Symmetry (E/A/T)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	2	4	ST

Requirements for Participation:

Preparation:
Basic knowledge of quantum mechanics

Form of Testing and Examination:
Oral Examination

Length of Course:
1 semester

Aims of the Course:
Understanding the fundamental concepts of representation theory and its application to describe the symmetry of molecules

Contents of the Course:
The lecture introduces to group theory with special emphasis on representations and their use to describe the symmetry of molecules in high-resolution spectroscopy and in molecular physics generally. The theory is accompanied by a series of "prototypical" examples Topics covered are
- symmetry in general and symmetry of a molecule.
- groups and point groups.
- irreducible representations, characters.
- vanishing integral rule
- the Complete Nuclear Permutation-Inversion (CNPI) group.
- the Molecular Symmetry (MS) group).
- the molecular point group.
- classification of molecular states: electronic, vibrational, rotational, and nuclear spin states
- nuclear spin statistical weights
- hyperfine structure
- non-rigid molecules (inversion, internal rotation)

Recommended Literature:
Jensen: Script (text of powerpoint presentation files; available during the course)
P. Jensen and P. R. Bunker: The Symmetry of Molecules, in: "Encyclopedia of Chemical Physics and Physical Chemistry" (J. H. Moore and N. D. Spencer, Eds.), IOP Publishing, Bristol, 2001.
P. R. Bunker and Per Jensen: "Molecular Symmetry and Spectroscopy, 2nd Edition," NRC Research Press, Ottawa, 1998 (ISBN 0-660-17519-3).
P. R. Bunker and P. Jensen: "Fundamentals of Molecular Symmetry", IOP Publishing, Bristol, 2004 (ISBN 0-7503-0941-5).

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Physical biology (T/A)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	4+2	8	ST

Requirements for Participation:

Preparation:
Advanced statistical mechanics

Form of Testing and Examination:
Oral examination

Length of Course:
1 semester

Aims of the Course:
Acquaintance with basic concepts of molecular and evolutionary biology; understanding of statistical issues arising in the analysis of sequence data and the application of methods from statistical physics addressing them.

Contents of the Course:
Statistics of the genome
Sequence analysis and sequence alignement
Evolutionary theory and population genetics
Theory of bio-molecular networks

Recommended Literature:
J.H. Gillespie, Population Genetics: A concise guide (Johns Hopkins University Press, 2004)
R. Durbin, S.R. Eddy, A. Krogh, G. Mitchison, Biological Sequence Analysis: Probabilistic Models of Proteins and Nucleic Acids (Cambridge University Press, 1998)
F. Kepes, Biological Networks (World Scientific, Singapore 2007)
D.J. Wilkinson, Stochastic Modelling for Systems Biology (Chapman&Hall, 2006)

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Statistical physics of soft matter and biomolecules (T/A)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	4+2	8	ST

Requirements for Participation:

Preparation:
Advanced statistical mechanics

Form of Testing and Examination:
Oral examination

Length of Course:
1 semester

Aims of the Course:
Understanding the molecular structure and mesoscopic properties of various types of soft matter systems, in particular with regard to their role in living cells.

Contents of the Course:
Colloids, polymers and amphiphiles
Biopolymers and proteins
Membranes
Physics of the cell

Recommended Literature:
J. K. G. Dhont, An Introduction to Dynamics of Colloids (Elsevier, Amsterdam, 1996).
M. Doi and S. F. Edwards, The Theory of Polymer Dynamics (Clarendon Press, Oxford, 1986).
S. A. Safran, Statistical Thermodynamics of Surfaces, Interfaces, and Membranes (Addison-Wesley, Reading, MA, 1994).
G. Gompper, U. B. Kaupp, J. K. G. Dhont, D. Richter, and R. G. Winkler, eds., Physics meets Biology — From Soft Matter to Cell Biology, vol. 19 of Matter and Materials (FZ Jülich, Jülich, 2004).
D. H. Boal, Mechanics of the Cell (Cambridge University Press, Cambridge, 2002).

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Statistical physics far from equilibrium (T)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	4+2	8	ST

Requirements for Participation:

Preparation:
Advanced statistical mechanics

Form of Testing and Examination:
Oral examination

Length of Course:
1 semester

Aims of the Course:
Understanding the generic behavior of fluctuation-dominated systems far from equilibrium, and acquaintance with the basic mathematical tools used for their description.

Contents of the Course:
Stochastic methods
Transport processes
Scale-invariant growth
Pattern formation far from equilibrium

Recommended Literature:
P.L. Krapivsky, S. Redner and E. Ben-Naim: A kinetic view of statistical physics (Cambridge University Press, 2010)
M. Kardar, Statistical Physics of Fields (Cambridge University Press, 2007)

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Disordered systems (T)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	4+2	8	ST

Requirements for Participation:

Preparation:
Advanced statistical mechanics

Form of Testing and Examination:
Oral examination

Length of Course:
1 semester

Aims of the Course:
Understanding the novel types of behaviour that arise in systems with quenched disorder, as well as the specific mathematical challenges associated with their theoretical description.

Contents of the Course:
Disorder average
Replica methods
Percolation
Phase transitions in disordered systems
Localization
Glassy dynamics

Recommended Literature:
D. Stauffer and A..Aharony, Introduction to Percolation Theory (Taylor & Francis, London 1994)
K.H. Fischer and J.A. Hertz, Spin Glasses (Cambridge University Press, Cambridge 1991)
K. Binder and W. Kob, Glassy Materials and Disordered Solids (World Scientific, Singapore 2005)
T. Nattermann, lecture notes

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Nonequilibrium physics with interdisciplinary applications (T)

Course No.:

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

Requirements for Participation:

Preparation:
Statistical mechanics

Form of Testing and Examination:
Oral examination or term paper

Length of Course:
1 semester

Aims of the Course:
Acquaintance with basic concepts of nonequilibrium physics; ability to apply the basic methods for the investigation of nonequilibrium problems; application of physics-based models to interdisciplinary problems.

Contents of the Course:
Principles of nonequilibrium physics
Stochastic systems and their desription (master equation, Fokker-Planck equation,..)
Analytical and numerical methods
Nonequilibrium phase transitions
Applications to traffic, pedestrian dynamics, economic systems, biology, pattern formation,..

Recommended Literature:
A. Schadschneider, D. Chowdhury, K. Nishinari: Stochastic Transport in Complex Systems (Elsevier, 2010)
P.L. Krapivsky, S. Redner, E. Ben-Naim: A Kinetic View of Statistical Physics (Cambridge University Press, 2010)
V. Privman (Ed.): Nonequilibrium Statistical Mechanics in One Dimension (Cambridge University Press, 1997)
N.G.Van Kampen: Stochastic Processes in Physics and Chemistry (Elsevier, 1992)

Module: Elective Advanced Lectures: BCGS Courses

Module No.: physics70d

Course: Probability theory and stochastic processes for physicists (T)

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	3	4	WT

Requirements for Participation:

Preparation:
Statistical mechanics on the bachelor level

Form of Testing and Examination:
Oral examination or term paper

Length of Course:
1 semester

Aims of the Course:
Acquaintance with probabilistic concepts and stochastic methods commonly used in the theory of disordered systems and nonequilibrium phenomena, as well as in interdisciplinary applications of statistical physics.

Contents of the Course:
Limit laws and extremal statistics
Point processes
Markov chains and birth-death processes
Stochastic differential equations and path integrals
Large deviations and rare events

Recommended Literature:
D. Sornette: Critical Phenomena in Natural Sciences (Springer, 2004)
N.G.Van Kampen: Stochastic Processes in Physics and Chemistry (Elsevier, 1992)

Module No.: physics910
Credit Points (CP): 15
Category: Required
Semester: 3.

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Scientific Exploration of the Master Thesis Topic

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Scientific Exploration of the Master Thesis Topic	physics911	15		450 hrs	WT

Requirements for Participation:
Successful completion of 60 credit points from the first year of the Master phase, including 7 cp from the Module physics601, 7 cp from the Elective Course Theoretical Physics and 24 cp from the Specialization Modules

Form of Examination:
Presentation

Content:
Under guidance of the supervisor of the Master Thesis topic, the student shall explore the science field, read the relevant recent literature, and perhaps participate in further specialised classes and in seminars. The student shall write an essay about the acquired knowledge, which may serve as the introduction part of the M.Sc. Thesis

Aims/Skills:
The student shall demonstrate to have understood the scientific question to be studied in the Master Thesis

Course achievement/Criteria for awarding cp's:
none

Length of Module: 1 semester

Maximum Number of Participants: ca. 100

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

Useable for:
Masterstudiengang Physik, Pflicht, Semester: 3

Module No.: physics920
Credit Points (CP): 15
Category: Required
Semester: 3.

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Methods and Project Planning

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Methods and Project Planning	physics921	15		450 hrs	WT

Requirements for Participation:
Successful completion of 60 credit points from the first year of the Master phase, including 7 cp from the Module physics601, 7 cp from the Elective Course Theoretical Physics and 24 cp from the Specialization Modules

Form of Examination:
Written proposal

Content:
Under guidance of the supervisor of the planned Master Thesis topic, the student shall acquire knowledge about the methods required to carry out the Master Thesis project. This may include the participation in specialised seminars or specialised classes for the master programme. The student shall plan the steps needed to successfully complete the Master Thesis

Aims/Skills:
The student shall demonstrate to have understood the methods to be used in the Master Thesis research. The project plan has to be presented

Course achievement/Criteria for awarding cp's:
none

Length of Module: 1 semester

Maximum Number of Participants: ca. 100

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

Useable for:
Masterstudiengang Physik, Pflicht, Semester: 3

Module No.: physics930
Credit Points (CP): 30
Category: Required
Semester: 4.

Fachgruppe
Physik und Astronomie
Universität Bonn

Module: Master Thesis

Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Master Thesis	physics931	30		900 hrs	ST

Requirements for Participation:
Successful completion of 60 credit points from the first year of the Master phase, including 7 cp from the Module physics601, 7 cp from the Elective Course Theoretical Physics and 24 cp from the Specialization Modules

Form of Examination:
Master Thesis

Content:
Under guidance of the supervisor of the Master Thesis topic, the student shall carry out the research of the Master Thesis project

Aims/Skills:
The student shall demonstrate to be able to do research

Course achievement/Criteria for awarding cp's:
Oral presentation

Length of Module: 1 semester

Maximum Number of Participants: ca. 100

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

Useable for:
Masterstudiengang Physik, Pflicht, Semester: 4

Modul-Nr.: add. Courses
Leistungspunkte:
Kategorie:
Semester:

Fachgruppe
Physik und Astronomie
Universität Bonn

Modul: additional courses

Modulbestandteile:

Nr.	LV Titel	LV Nr	LP	LV-Art	Aufwand	Sem.
1.	Physics in the Private Sector	PhysPrivSec	0		90 hrs	

Zulassungsvoraussetzungen:

Empfohlene Vorkenntnisse:

Inhalt:

Lernziele/Kompetenzen:

Prüfungsmodalitäten:

Dauer des Moduls:

Max. Teilnehmerzahl:

Anmeldeformalitäten:

Modul: additional courses

Modul-Nr.: add. Courses

Lehrveranstaltung: Physics in the Private Sector

LV-Nr.: PhysPrivSec

Kategorie	LV-Art	Sprache	SWS	LP	Semester
Elective	Lecture with exercises	English	2+1	0	

Zulassungsvoraussetzungen:

Empfohlene Vorkenntnisse:
Mathematical, theoretical and experimental foundations in physics

Studien- und Prüfungsmodalitäten:
Requirements for the module examination (written examination): successful work with exercises

Dauer der Lehrveranstaltung:
1 semester

Lernziele der LV:
The vast majority of graduates with a physics degree or a doctorate in physics work in the private sector in very different areas, ranging from industrial research and software development to management consultancies, financial institutions and patent attorneys. In this lecture, the basics of these different fields are explained, deepened in the exercises and supplemented by guest lectures by physicists from the private sector.

Successful participants will receive a document about their attendance and the course contents.

Inhalte der LV:
- Management Consulting
- Financial Physics
- Professional Software Development
- Patent Law
- Physics in Insurances
- Simulations in Physics
- Entrepreneurship

Literaturhinweise:
- Grundprinzipien der Finanz- und Versicherungsmathematik: Grundlagen und Anwendungen der Bewertung von Zahlungsströmen, Peter Albrecht
- Patentrecht für Studierende der Naturwissenschaften: Eine kompakte Einführung in die Grundlagen, Gernot Krobath
- A Friendly Guide to Software Development: What You Should Know Without Being a Developer (Friendly Guides to Technology) (English Edition), Leticia Portella
- Cracked it!: How to solve big problems and sell solutions like top strategy consultants, Bernard Garrette , Corey Phelps