

**Module-Handbook**  
**Master in Physics**  
**PO von 2006**

**SS 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](https://www.physik-astro.uni-bonn.de/de/studium/lehrveranstaltungen/termine-und-lehrveranstaltungen)

# Master in Physics, University of Bonn

1 <sup>st</sup> Term				
physics600	physics605	physics610		physics700
<b>Base Module: Laboratory Course</b>	<b>Base Module: Theoretical Physics</b>	<b>Specialization I</b>		<b>Elective Advanced Lectures</b>
7 CP	7 CP	12 CP		(a)
2 <sup>nd</sup> Term				
physics630	physics710	physics720	physics730	physics650
<b>Specialization II</b>	<b>Experimental Physics</b>	<b>Applied Physics</b>	<b>Theoretical Physics</b>	<b>Seminar</b>
12 CP	(a)			4 CP
3 <sup>rd</sup> Term				
physics910	physics920			
<b>Scientific Exploration of Master Thesis Topic</b>	<b>Methods and Project Planning</b>			
15 CP	15 CP			
4 <sup>th</sup> Term				
physics930				
<b>Master Thesis</b>				
30 CP				

Notes: The students must achieve the indicated number of CP (Credit Points).

(a): In the modules 700, 710, 720, 730 at least 18 CP altogether must be achieved.



**Abbreviations:**

CP	Credit Points ( <i>Leistungspunkte</i> )
ex.	exercises
hrs	hours
lab.	laboratory
Ma-PO	"Master-Prüfungsordnung" (Examination Regulations (Master Course))
n.a.	not applicable
ST	Summer Term
TH	Teaching Hours
WT	Winter Term
E	Experimental Physics
A	Applied Physics
T	Theoretical Physics

On proposal of the board of examination, the Dean may agree to further compulsory selectable (sub-) modules. The office of the board of examination will announce these compulsory selectable (sub-) modules agreed upon, electronically or by public notice, in due time before the beginning of the semester.

**Note about programme language:**

The M.Sc. in Physics programme is a programme in English language. At the discretion of the lecturer and the class German language may be used as the teaching language as well. Furthermore non-German speaking students are expected to learn German language on their own accord during the course of this programme.

**Note to the points "Requirements" and "Preparation":**

The point "Requirements" contains courses that have to be passed in order for the students to be able to participate in the module.

The point "Preparation" contains other courses whose content helps significantly towards the understanding of this course.

**Note about module (submodule) examinations:**

The details about the submodule examination will be announced by the lecturer before the start of the lecture

Please find updated versions of the module-handbook at <http://www.physik-astro.uni-bonn.de>

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<b>Module No.:</b>	physics600
<b>Credit Points (CP):</b>	7
<b>Category:</b>	Required
<b>Semester:</b>	7.



## Module: Base Module Laboratory Course

**Requirements:****Preparation:****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

**Form of Testing and Examination:**

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  $\geq 9$  are required.

Requirements for the submodule examination (written report for every laboratory): successful completion of the experiment and initial oral questioning

**Length of Module:** 1 semester

**Maximum Number of Participants:** 60

**Registration Procedure:**

s. <https://basis.uni-bonn.de> u. <http://bamawww.physik.uni-bonn.de>

Module No.: physics605  
 Credit Points (CP): 7  
 Category: Required  
 Semester: 7.



## Module: Base Module Theoretical Physics

### Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Advanced Quantum Theory	physics606	7	Lect. + ex.	210 hrs	WT
2.	Advanced Theoretical Physics	physics607	7	Lect. + ex.	210 hrs	WT

### Requirements:

### Preparation:

### Content:

The course provides fundamental knowledge needed for theoretical lectures in the Master course

### Aims/Skills:

The M.Sc. Physics programme includes one obligatory module for all students. It includes a theoretical unit to extend the B.Sc. in Physics knowledge

### Form of Testing and Examination:

Requirements for the module examination (written examination): successful work with 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>

Note: When the student has (upon admission) demonstrated satisfactory knowledge of Advanced Quantum Theory already, the class Advanced Theoretical Physics may be taken instead

**Module: Base Module Theoretical Physics**

Module No.: physics605

**Course:**  **Advanced Quantum Theory**

Course No.: physics606

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

**Requirements:****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)

**Module: Base Module Theoretical Physics**

Module No.: physics605

**Course:**  **Advanced Theoretical Physics**

Course No.: physics607

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

**Requirements:****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.: physics610  
 Credit Points (CP): 12  
 Category: Elective  
 Semester: 7.



## Module: Specialization I

### Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
<b>Particle Physics</b>						
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
<b>Condensed Matter and Photonics</b>						
1.	Condensed Matter Physics	physics613	6	Lect. + ex.	180 hrs	WT
2.	Condensed Matter Physics I	CondMatter I	6	Lect. + ex.	180 hrs	WT
3.	Applied Photonics	physics619	6	Lect. + ex.	180 hrs	WT
4.	Advanced Atomic, Molecular, and Optical Physics	physics620	6	Lect. + ex.	180 hrs	WT
5.	Molecular Physics I	MolPhys I	6	Lect. + ex.	180 hrs	WT
<b>Theoretical Physics</b>						
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:

#### Preparation:

See with the description of the course

#### Content:

Teaching of advanced fundamentals of physics from two research areas of physics in Bonn

#### Aims/Skills:

The students will get acquainted with two research topics of today

#### Form of Testing and Examination:

Requirements for the submodule examination (written or oral examination): successful work with 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>

Note: The student must achieve 12 CP from two different specialization areas (Particle Physics; Condensed Matter and Photonics; Theoretical Physics)

**Module: Specialization I**

Module No.: physics610

**Course: universität  Particle Physics**

Course No.: physics611

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

**Requirements:****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 I**

Module No.: physics610

**Course:**  **Accelerator Physics**

Course No.: physics612

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

**Requirements:****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 I**

Module No.: physics610

**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:****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 I**

Module No.: physics610

**Course:**  universität**bonn**
**Condensed Matter Physics**

Course No.: physics613

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

**Requirements:****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, Festkörperphysik (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 I**

Module No.: physics610

**Course:****Condensed Matter Physics I**

Course No.:

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

**Requirements:****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 I**

Module No.: physics610

**Course:**  **Applied Photonics**

Course No.: physics619

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

**Requirements:****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:**

To make the students understand physical and technological foundations of photonics and enable them to practically apply their knowledge in research and development.

**Contents of the Course:**

Optics: Rays, Beams, Waves;  
Waveguides, Fibers

Light sources; Detectors; Imaging devices

Optical amplification; Acoustooptics, electrooptics

Photonic circuits, optical communication

Optical Metrology (angle, distance, velocity, density...);

Material Processing (cutting, welding, lithography, lasers in medicine)

**Recommended Literature:**

D. Meschede; Optik, Licht und Laser (Teubner, Wiesbaden 2. überarb. Aufl. 2005)

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)

**Module: Specialization I**

Module No.: physics610

**Course:**  universität**bonn**
**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:****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 I**

Module No.: physics610

**Course:****Molecular Physics I**

Course No.:

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

**Requirements:****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 &amp; 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: Specialization I**

Module No.: physics610

**Course:**  **Theoretical Particle Physics**

Course No.: physics615

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

**Requirements:****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 I**

Module No.: physics610

**Course:**  **Theoretical Hadron Physics**

Course No.: physics616

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

**Requirements:****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 I**

Module No.: physics610


**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:****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 I**

Module No.: physics610

**Course:****Solid State Theory I**

Course No.:

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

**Requirements:****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.: physics630  
 Credit Points (CP): 12  
 Category: Elective  
 Semester: 8.



## Module: Specialization II

### Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
<b>Particle Physics</b>						
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
<b>Condensed Matter and Photonics</b>						
1.	Magnetism/Superconductivity	physics634	6	Lect. + ex.	180 hrs	ST
2.	Laser Spectroscopy	physics635	6	Lect. + ex.	180 hrs	ST
3.	Molecular Physics II	MolPhys II	6	Lect. + ex.	180 hrs	ST
<b>Theoretical Physics</b>						
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:

### Preparation:

### Content:

In depth knowledge on the basics of the research programme in physics at Bonn University

### Aims/Skills:

The students shall learn the basics as well as the present state of current research in the fields

### Form of Testing and Examination:

Requirements for the submodule examination (written or oral examination): successful work with 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>

Note: The student must achieve 12 CP from one or two specialization areas.

**Module: Specialization II**

Module No.: physics630

**Course:**  **Physics of Hadrons**

Course No.: physics632

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

**Requirements:****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 II**

Module No.: physics630

**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:****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 II**

Module No.: physics630

**Course:**  universität**bonn**
**Advanced Topics in High Energy Particle Physics**

Course No.: physics639

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

**Requirements:****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 II**

Module No.: physics630

**Course:**  universität**bonn**
**Magnetism/Superconductivity**

Course No.: physics634

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

**Requirements:****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 II**

Module No.: physics630

**Course:**  universität**bonn****Laser Spectroscopy**

Course No.: physics635

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

**Requirements:****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:**

Make the students understand the principles of spectroscopy and enable them to practically apply their knowledge in research and development.

**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.  
 Single molecule spectroscopy; spectroscopy at interfaces & surfaces  
 Advanced optical imaging;  
 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: Specialization II**

Module No.: physics630

**Course:****Molecular Physics II**

Course No.:

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

**Requirements:****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 atmospheric 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: Specialization II**

Module No.: physics630

**Course:**  universität**bonn**
**Advanced Theoretical Particle Physics**

Course No.: physics636

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

**Requirements:****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 supersymmetry, (Phys.Res. 128 C (1985) 39)  
 P. Freund; Introduction to Supersymmetry (Cambridge University Press 1995)

**Module: Specialization II**

Module No.: physics630

**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:****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 II**

Module No.: physics630

**Course:**  universität**bonn**
**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:****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.:

physics700

Credit Points (CP):

Category:

Elective

Semester:

7.



## Module: Elective Advanced Lectures

### Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
<b>Particle Physics</b>						
1.	Selected 700-courses from catalogue	physics711-729	4-6	see catalogue	120-180 hrs	WT/ST
<b>Condensed Matter and Photonics</b>						
1.	Selected 700-courses from catalogue	physics731-749	3-6	see catalogue	90-180 hrs	WT/ST
<b>Theoretical Physics</b>						
1.	Selected 700-courses from catalogue	physics751-769	5-7	see catalogue	150-210 hrs	WT/ST
<b>Special Topics</b>						
1.	Selected 700-courses from catalogue	physics771-779	3-6	see catalogue	90-180 hrs	WT/ST
<b>Research Internship</b>						
1.	Internships in the Research Groups	physics799	4	internship		WT/ST
<b>Cologne Courses</b>						
1.	Courses from Cologne marked "E", "A", or "T"	see catalogue	3-8	see catalogue	90-240 hrs	WT/ST
1.	Also possible classes from M.Sc. in Astrophysics					

### Requirements:

### Preparation:

### Content:

Special lectures on research topics of the physics section of the Bonn University

### Aims/Skills:

The students are offered the opportunity to get insight into today's research problems

### Form of Testing and Examination:

If the lecture is offered with exercises: requirements for the module examination (written or oral examination): successful work with 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>

Note: The students must obtain 18 CP in all out of the modules physics700, -710, -720, -730.

Module No.: physics710  
 Credit Points (CP):  
 Category: Elective  
 Semester: 8.



# Module: Experimental Physics

**Module Elements:**

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Selected 700-courses from catalogue type "E" (Experimental) or "E/A" (E/Applied)	see catalogue	3-6	see catalogue	90-180 hrs	ST/WT
2.	Courses from Cologne marked "E"	see catalogue	3-5	see catalogue	90-150 hrs	WT/ST
3.	Also possible classes from M.Sc. in Astrophysics					

**Requirements:**

**Preparation:**

**Content:**

Advanced lectures in experimental physics from the catalogue of selected courses

**Aims/Skills:**

Preparation for Master's Thesis work; broadening of scientific knowledge

**Form of Testing and Examination:**

If the lecture is offered with exercises: requirements for the submodule examination (written or oral examination): successful work with 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>

Note: The students must obtain 18 CP in all out of the modules physics700, -710, -720, -730.

Module No.:  
 Credit Points (CP):  
 Category:  
 Semester:

physics720  
 Elective  
 8.



## Module: Applied Physics

### Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Selected 700-courses from catalogue type "A" (Applied) or "E/A" (Experimental/A)	see catalogue	3-6	see catalogue	90-180 hrs	ST/WT
2.	Courses from Cologne marked "A"	see catalogue	3-8	see catalogue	90-240 hrs	WT/ST
3.	Also possible classes from M.Sc. in Astrophysics					

### Requirements:

### Preparation:

### Content:

Advanced lectures in applied physics from the catalogue of selected courses

### Aims/Skills:

Preparation for Master's Thesis work; broadening of scientific knowledge

### Form of Testing and Examination:

If the lecture is offered with exercises: requirements for the submodule examination (written or oral examination): successful work with 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>

Note: The students must obtain 18 CP in all out of the modules physics700, -710, -720, -730.

Module No.:  
 Credit Points (CP):  
 Category:  
 Semester:

physics730  
 Elective  
 8.



## Module: Theoretical Physics

### Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Selected 700-courses from catalogue type "T" (Theoretical)	see catalogue	3-7	see catalogue	90-210 hrs	ST/WT
2.	Courses from Cologne marked "T"	see catalogue	4-8	see catalogue	120-240 hrs	WT/ST
3.	Also possible classes from M.Sc. in Astrophysics					

### Requirements:

### Preparation:

### Content:

Advanced lectures in theoretical physics from the catalogue of selected courses.

### Aims/Skills:

Preparation for Master's Thesis work; broadening of scientific knowledge

### Form of Testing and Examination:

Requirements for the submodule examination (written examination): successful 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>

Note: The students must obtain 18 CP in all out of the modules physics700, -710, -720, -730.

Module No.:  
Credit Points (CP):  
Category:  
Semester:

physics650  
4  
Elective  
8.



## Module: Seminar

### Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
1.	Seminars on Current Topics in Particle Physics		4	seminar	120 hrs	ST
2.	Seminars on Current Topics in Condensed Matter and Photonics		4	seminar	120 hrs	ST
3.	Seminars on Current Topics in Theoretical Physics		4	seminar	120 hrs	ST

### Requirements:

### Preparation:

### Content:

Topics from the research areas covered by the research group, 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

### Form of Testing and Examination:

Presentation of the topic

**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>



Module No.: physics910  
 Credit Points (CP): 15  
 Category: Required  
 Semester: 9.



## 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:**

Successful completion of 40 credit points from the first year of the Master phase, including the Base Modules physics600 and physics605 and the Specialization Modules physics610 and physics630

### **Preparation:**

### **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

### **Form of Testing and Examination:**

Essay

**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 No.:  
Credit Points (CP):  
Category:  
Semester:

physics920  
15  
Required  
9.



## 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:**

Successful completion of 40 credit points from the first year of the Master phase, including the Base Modules physics600 and physics605 and the Specialization Modules physics610 and physics630

### **Preparation:**

### **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

### **Form of Testing and Examination:**

Short proposal for Master Thesis

**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 No.: physics930  
 Credit Points (CP): 30  
 Category: Required  
 Semester: 10.



## Module: Master Thesis

### Module Elements:

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

### **Requirements:**

Successful completion of the preparatory phase for the Master Thesis (physics910 and physics920)

### **Preparation:**

### **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

### **Form of Testing and Examination:**

Master Thesis and 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>

# Catalogue of 700-courses in Particle Physics

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**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:****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 ladder, 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:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **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:****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:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **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:****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)

<b>Modules:</b>	physics700 <b>Elective Advanced Lectures</b> physics710 <b>Experimental Physics</b> physics720 <b>Applied Physics</b>
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**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:****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 &amp; Sons 1993)

A. Chao; Physics of Collective Beam Instabilities in High Energy Accelerators (Wiley &amp; Sons 1993)

Script of the Lecture Particle Accelerators (physics612)

<http://www-elsa.physik.uni-bonn.de/~hillert/Beschleunigerphysik/>



**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**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:****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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**Course:**

## 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:****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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**Course:****High Energy Physics Lab (E)**

Course No.: physics717

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

**Requirements:****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:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **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:****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:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**Course:****Physics with Antiprotons (E)**

Course No.: physics720

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

**Requirements:****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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**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	3	4	WT/ST

**Requirements:****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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**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:****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

Catalogue of  
700-courses in  
Condensed Matter &  
Photonics



**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **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:****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:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **Applied Physics**

**Course:****Optics Lab (E/A)**

Course No.: physics732

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

**Requirements:****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:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **Applied Physics**

**Course:****Holography (E/A)**

Course No.: physics734

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

**Requirements:****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:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**Course:**

## Laser Cooling and Matter Waves (E)

**Course No.:** physics735

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

**Requirements:****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:**  
 physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **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:**

**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 Magneto-optics & Magneto-optical 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:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**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	3	4	WT/ST

**Requirements:****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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**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:****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:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **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:****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:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **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:****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:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **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:****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:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics730 **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:****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 &amp; 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)

# Catalogue of 700-courses in Theoretical Physics

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics730 **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:****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 &amp; 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)

<b>Modules:</b>	physics700 <b>Elective Advanced Lectures</b> physics730 <b>Theoretical Physics</b>
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**Course:**  **Group Theory (T)**

**Course No.:** physics751

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

**Requirements:**

**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:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**Course:****Superstring Theory (T)**

Course No.: physics752

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

**Requirements:****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 &amp; II (Cambridge University Press 1988)

H.P. Nilles, Supersymmetry and phenomenology (Phys. Repts. 110 C (1984) 1)

J. Polchinski; String Theory I &amp; II (Cambridge University Press 2005)

**Modules:** physics700 **Elective Advanced Lectures**  
physics730 **Theoretical Physics**

**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:**

**Preparation:**

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

**Form of Testing and Examination:**

Requirements for the examination (written): successful work with the exercises

**Length of Course:**

1 semester

**Aims of the Course:**

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

**Contents of the Course:**

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

**Recommended Literature:**

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



**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **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:****Preparation:**

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

**Form of Testing and Examination:**

Requirements for the examination (written): successful work with the exercises

**Length of Course:**

1 semester

**Aims of the Course:**

Understanding the general theory of relativity and its cosmological implications

**Contents of the Course:**

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

**Recommended Literature:**

S.Weinberg; Gravitation and Cosmology (J. Wiley & Sons 1972)  
 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:** physics700 **Elective Advanced Lectures**  
physics730 **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:**

**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:** physics700 **Elective Advanced Lectures**  
physics730 **Theoretical Physics**

**Course:**  **Critical Phenomena (T)**

**Course No.:** physics756

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

**Requirements:**

**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. Nersisyan, A.N.Tsvetik; Bosonisation and strongly correlated systems (Cambridge University Press, 1998)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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)

**Modules:** physics700 **Elective Advanced Lectures**  
physics730 **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:**

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:** physics700 **Elective Advanced Lectures**  
physics730 **Theoretical Physics**

**Course:**  **Supersymmetry (T)**

**Course No.:** physics761

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

**Requirements:**  
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.

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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, Cambridge 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



**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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. Repts. 110C (1984)1)  
 J. Polchinski: String Theory I & II (Cambridge University Press 2005)

**Modules:** physics700 **Elective Advanced Lectures**  
physics730 **Theoretical Physics**

**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:**

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 on arXiv.org [hep-th]

J. Polchinski: String Theory I & II

S. Weinberg: Quantum Theory of Fields

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:**

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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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

**Modules:** physics700 **Elective Advanced Lectures**  
physics730 **Theoretical Physics**

**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:**

**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

**Modules:** physics700 **Elective Advanced Lectures**  
physics730 **Theoretical Physics**

**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:**

**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:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**Course:****Random Walks and Diffusion (T)**

Course No.: physics7502

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

**Requirements:****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



**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****Preparation:**

- + Introductory Condensed Matter Theory
- + Quantum Mechanics
- + Statistical Physics

**Form of Testing and Examination:**

oral or written examination

**Length of Course:**

1 semester

**Aims of the Course:**

Knowledge of topics of contemporary condensed matter research  
 Knowledge of theoretical methods of condensed matter physics

**Contents of the Course:**

Covers topics and methods of contemporary research, such as

- + Feynman diagram technique
- + Phase transitions and critical phenomena
- + Topological aspects of phenomena in condensed matter physics

**Recommended Literature:**

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

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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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  $^3\text{He}$ , superconductivity in heavy fermion compounds, high temperature superconductivity and open questions.

**Recommended Literature:**

Will be announced in the first lecture

# Catalogue of 700-courses in Special Topics

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics720 **Applied Physics**

**Course:**

## Environmental Physics & Energy Physics (A)

Course No.: physics771

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

**Requirements:****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, Oldenbourg 1998  
 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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics720 **Applied Physics**

**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:****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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics720 **Applied Physics**

**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:****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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **Applied Physics**

**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:****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. Horowitz, 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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics720 **Applied Physics**

**Course:****Nuclear Reactor Physics (A)**

Course No.: physics775

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

**Requirements:****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 (fission 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 &amp; Sons (2007)



**Modules:** physics700 **Elective Advanced Lectures**  
physics720 **Applied Physics**

**Course:**  universität**bonn**

## 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:**

**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

# Cologne Courses in General Relativity and Quantum Field Theory

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**Course:****Geometry in Physics (T)**

Course No.:

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

**Requirements:****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.

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**Course:****Topology for Physicists (T)**

Course No.:

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

**Requirements:****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)



# Cologne Courses in Nuclear and Particle Physics

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**Course:****Nuclear physics II (E)**

Course No.:

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

**Requirements:****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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **Applied Physics**

**Course:****Physics of Detectors (E/A)**

Course No.:

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

**Requirements:****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 neutral particles: neutrons and neutrinos
- Measurement of 4-momentum in particle physics
- Ionisation detectors: Bragg chamber, avalanche detectors
- Position sensitive detectors: drift chambers, time-projection 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 analogue 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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**Course:****Particle physics (E)**

Course No.:

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

**Requirements:****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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**Course:**

## Groundbreaking experiments in nuclear physics (E)

**Course No.:**

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

**Requirements:****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
- Hofstadter's electron scattering experiments
- The use of cosmic rays to discover mesons
- Fermi work in neutron physics
- Properties of neutrinos
- Mößbauer effect

**Recommended Literature:**

Will be distributed during the course.

# Cologne Courses in Condensed Matter Physics

**Module: Specialization I**

Module No.: physics610

**Course:****Condensed Matter Physics I**

Course No.:

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

**Requirements:****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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**

**Course:****Condensed Matter Physics II (E)**

Course No.:

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

**Requirements:****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



**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **Applied Physics**

**Course:**

## Semiconductor Physics and Nanoscience (E/A)

**Course No.:**

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

**Requirements:****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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **Applied Physics**

**Course:****Superconductivity (E/A)**

Course No.:

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

**Requirements:****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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **Applied Physics**

**Course:****Magnetism (E/A)**

Course No.:

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

**Requirements:****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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **Applied Physics**

**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:****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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **Applied Physics**

**Course:**

## Physics of Surfaces and Nanostructures (E/A)

**Course No.:**

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

**Requirements:****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 emphasized. 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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **Applied Physics**

**Course:**

## Introduction to neutron scattering (E/A)

**Course No.:**

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

**Requirements:****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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **Applied Physics**

**Course:****Optical Spectroscopy (E/A)**

Course No.:

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

**Requirements:****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)

# Cologne Courses in Molecular Physics



**Module: Specialization I**

Module No.: physics610

**Course:****Molecular Physics I**

Course No.:

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

**Requirements:****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 &amp; 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: Specialization II**

Module No.: physics630

**Course:****Molecular Physics II**

Course No.:

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

**Requirements:****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 atmospheric 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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **Applied Physics**

**Course:****Astrochemistry (E/A)**

Course No.:

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

**Requirements:****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-VCH, Weinheim, 2010  
 J. Lequeux "The interstellar Medium" Springer, 2004  
 A. Shaw "Astrochemistry" Wiley, 2006  
 D. Whittet "Dust in the Galactic Environment", Taylor and Francis, 2nd edition, 2002

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics710 **Experimental Physics**  
 physics720 **Applied Physics**  
 physics730 **Theoretical Physics**

**Course:**

## Fundamentals of Molecular Symmetry (E/A/T)

**Course No.:**

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

**Requirements:****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).

# Cologne Courses in Statistical and Biological Physics

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics720 **Applied Physics**  
 physics730 **Theoretical Physics**

**Course:****Physical biology (T/A)**

Course No.:

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

**Requirements:****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 alignment  
 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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics720 **Applied Physics**  
 physics730 **Theoretical Physics**

**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:****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).

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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)



**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**Course:****Disordered systems (T)**

Course No.:

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

**Requirements:****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 &amp; 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

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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 description (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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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)

# Cologne Courses in Theoretical Solid State Physics

**Module: Specialization I**

Module No.: physics610

**Course: Solid State Theory I**

Course No.:

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

**Requirements:****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"

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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)

**Modules:**

physics700 **Elective Advanced Lectures**  
 physics730 **Theoretical Physics**

**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:****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)