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

Fachgruppe
Physik und Astronomie
Universität Bonn

# Module: Specialization: Experimental Physics

## Module Elements:

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

**Requirements for Participation:**

**Form of Examination:**
see with the course

**Content:**
Fundamentals in experimental physics in Bonn or Cologne

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

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

**Length of Module:** 1 semester

**Maximum Number of Participants:** ca. 100

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

Note: The student must achieve at least 24 CP out of all 6 Specialization Modules

# Module: Specialization: Experimental Physics

**Module No.:** physics61a

# Course: Particle Physics

**Course No.:** physics611

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

**Requirements for Participation:**

**Preparation:**
Introductory particle physics and quantum mechanics courses

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

**Length of Course:**
1 semester

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

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

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

# Module: Specialization: Experimental Physics

**Module No.:** physics61a

# Course: Accelerator Physics

**Course No.:** physics612

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

**Requirements for Participation:**

**Preparation:**

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

**Length of Course:**
1 semester

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

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

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

# Module: Specialization: Experimental Physics

**Module No.:** physics61a

# Course: universitätbonn Physics of Particle Detectors

**Course No.:** physics618

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

**Requirements for Participation:**

**Preparation:**
Useful: physik510

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

**Length of Course:**
1 semester

**Aims of the Course:**
Understanding the basics of the physics of particle detectors, their operation and readout

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

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

# Module: Specialization: Experimental Physics

**Module No.:** physics61a

# Course: Condensed Matter Physics

**Course No.:** physics613

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

**Requirements for Participation:**

**Preparation:**

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

**Length of Course:**
1 semester

**Aims of the Course:**
Understanding of the concepts of condensed matter physics

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

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

# Module: Specialization: Experimental Physics

**Module No.:** physics61a

# Course: universitätbonn Advanced Atomic, Molecular, and Optical Physics

**Course No.:** physics620

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

**Requirements for Participation:**

**Preparation:**
Fundamentals of Quantum Mechanics, Atomic Physics

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

**Length of Course:**
1 semester

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

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

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

Bose Condensation; Matterwave Optics

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

# Module: Specialization: Experimental Physics

**Module No.:** physics61a

# Course: Quantum Optics

**Course No.:** physics631

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

**Requirements for Participation:**

**Preparation:**

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

**Length of Course:**
1 semester

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

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

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

# Module: Specialization: Experimental Physics

**Module No.:** physics61a

# Course: Condensed Matter Physics I

**Course No.:**

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

**Requirements for Participation:**

**Preparation:**
Basic knowledge in condensed matter physics and quantum mechanics

**Form of Testing and Examination:**
Oral or written examination

**Length of Course:**
2 semesters

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

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

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

# Module: Specialization: Experimental Physics

**Module No.:** physics61a

# Course: Molecular Physics I

**Course No.:**

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

**Requirements for Participation:**

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

**Form of Testing and Examination:**
Oral Examination

**Length of Course:**
1 semester

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

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

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

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