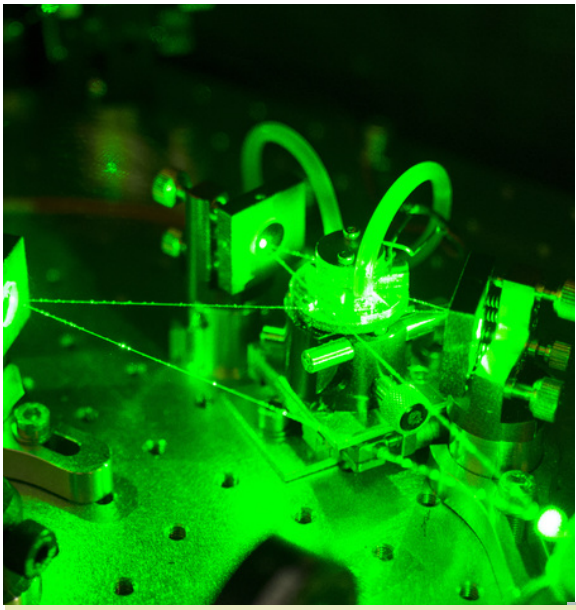
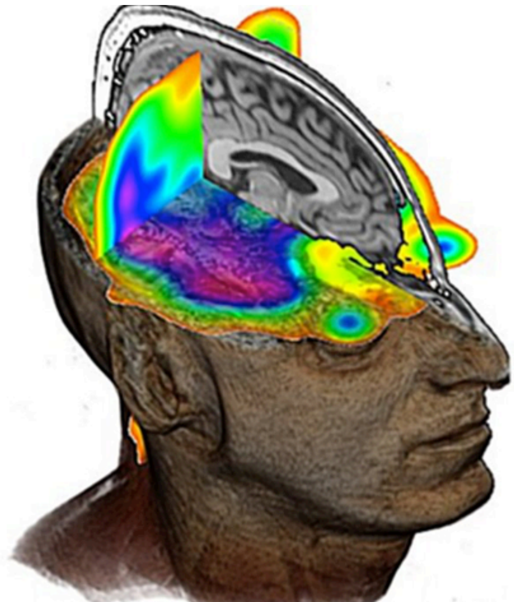
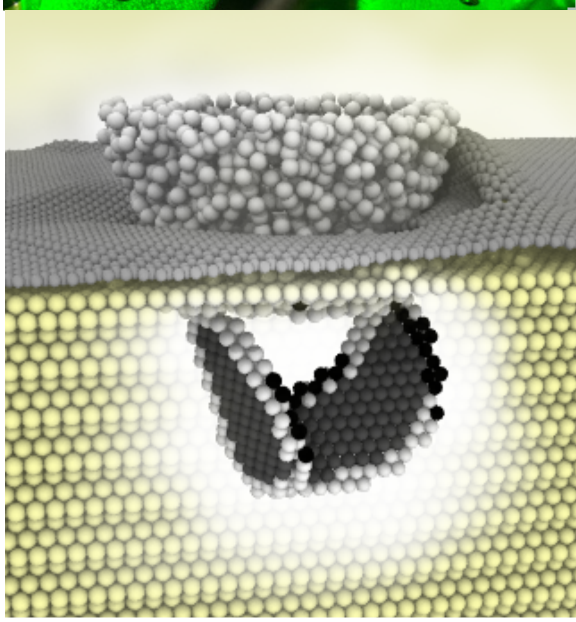
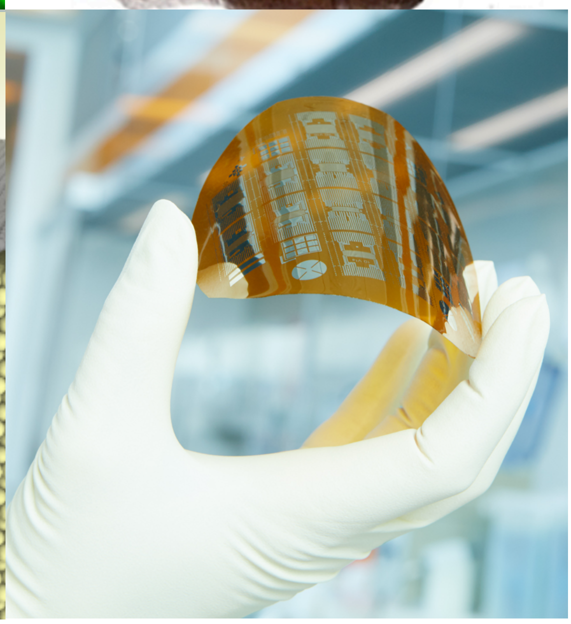
Handbook of Modules

Master-of-Science (M.Sc.)
Applied Physics

Physikalisches Institut
Fakultät für Mathematik und Physik
Albert-Ludwigs-Universität Freiburg

Fach / S*ubject*	Angewandte Physik / *Applied Physics*
Abschluss / D*egree*	Master of Science (M.Sc.)
Prüfungsordnung / *Examination regulations*	PO 2016
Art des Studiengangs / *Type of degree*	konsekutiv / *consecutive*
Studienform / *Study form*	Vollzeitstudium / f*ull time study*
Studiendauer / *Duration of study*	4 Semester (Regelstudienzeit) / *4 semester (regular duration of study)*
Unterrichtssprache / *Language of instruction*	englisch / *English*
Studienbeginn / *Start of studies*	Winter- oder Sommersemester / *winter or summer semester*
Hochschule / U*niversity*	Albert-Ludwigs-Universität Freiburg
Fakultät / F*aculty*	Fakultät für Mathematik und Physik / *Faculty for Mathematics and Physics*
Institut / I*nstitute*	Physikalisches Institut / *Institute of Physics*
Internetseite / W*ebsite*	www.physik.uni-freiburg.de
Profil des Studiengangs / *Profile of the study program*	*The English-taught M.Sc. Applied Physics aims to continue and broaden studies begun at the bachelor level. It provides an interdisciplinary study program at the interface between fundamental physical concepts and resulting modern technologies.* *In the first year of their studies, participants consolidate their knowledge by attending lectures on advanced theoretical and experimental physics, as well as courses in applied physics, which can be selected from a wide range of topics. In cooperation with associated institutes of the university, the university medical centre and with the Fraunhofer institutes in Freiburg, the Master's program offers the possibility for specialization in a particular area of applied physics, such as optical technologies, physics in life and medical sciences, or interactive and adaptive materials. During their final one-year Master thesis, students specialize in a particular field by participating in a cutting-edge research project in Applied Physics.* *The Master's program offers the possibility for an optional specialization in Quantum Science and Technology, if the students choose their courses accordingly*.
Ausbildungsziele / Qualifikationsziele des Studiengangs *Qualification goals of the study program*	Fachliche Qualifikationsziele / *Professional qualification goals*: ▪ *Consolidation of advanced knowledge in physics and its applications in physical sciences and related areas* ▪ *In-depth knowledge acquired in at least one specialist area of applied physics as defined by the master thesis topic and/or an optional specialization* ▪ *Ability to apply modern methods, techniques and concepts in physical sciences and related areas as well as to implement them efficiently* ▪ *Ability to develop and pursue a self-contained scientific project with adequate methods and to conduct independent research in a specialized field of applied physics* ▪ *Experience with working processes in joint research projects at research institutions and large-scale research facilities*

	■ *Capability to communicate scientific results in written reports and in presentations to an academic audience* Überfachliche Qualifikationsziele / *General qualification goals*: ■ *Ability to pursue independent, responsible and creative scientific work* ■ *Ability to organize, carry out and manage complex projects* ■ *Preparation to take on management responsibility and to supervise, lead and guide others* ■ *Ability to operate in a professional environment* ■ *Acquisition of abstraction skills, system-analytical thinking, teamwork and communication skills* ■ *International and intercultural experience* ■ *Social responsibility*
Zulassungs-voraussetzungen *Admission requirements*	Qualifizierter Bachelor-Abschluss in Physik oder einem gleichwertigen Studiengang. Außerdem / *Qualifying bachelor's degree in physics or an equivalent degree course. In addition* ■ mindestens 32 ECTS-Punkte in Theoretischer Physik ■ mindestens 32 ECTS-Punkte in Experimenteller Physik ■ mindestens 24 ECTS-Punkte in Mathematik ■ mindestens 18 ECTS-Punkte aus physikalischen Praktika ■ Bachelor-Arbeit in Physik (10 ECTS-Punkte) ■ Niveau B2 in Englisch

Preliminary remarks:

This module handbook does not replace the course catalog, which is updated and published every semester and contains current information on the courses (e.g. time, location and lecturer).

List of Abbreviations

M.Sc.	Master of Science
Credit hrs	A credit hour corresponds to a course of a duration of 45 minutes per week (in German: Semesterwochenstunden, SWS)
SL	Assessed coursework („Studienleistung"), ungraded; does not contribute to final grade
PL	Exam („Prüfungsleistung"), graded; contributes to final grade
L	Lecture
E	Exercise/Tutorials
S	Seminar
Lab	Laboratory
SoSe	Summer semester (summer term)
WiSe	Winter semester (winter term)
ECTS	Credit Points based on the European Credit Transfer System (ECTS-Points)

Table of Contents

1. The Master-of-Science (M.Sc.) Applied Physics

1.1. Structure

The Institute of Physics offers a research-oriented curriculum leading to a Master-of-Science degree in Applied Physics. The program comprises a total of 120 ECTS credit points, which are collected in various compulsory and elective modules as defined by the study regulations.

Module	Type	Contact hours	ECTS	Compusory/ Elective	Recomended semester	Assessment
Advanced Experimental Physics	L+E	4 + 2	9	E	1 or 2	SL: exercises PL: written or oral exam
Advanced Theoretical Physics	L+E	4 + 2	9	E	1 or 2	SL: exercises PL: written or oral exam
Applied Physics	L+E	variable	18	E	1 or 2	SL: exercises SL: written or oral exam (9 ECTS) PL: written or oral exam (9 ECTS)
Elective Subjects	L+E	variable	10	E	1 or 2	SL: exercises and/or written or oral exam
Term Paper	S	2	6	E	1 or 2	PL: presentation and written report
Master Laboratory Applied Physics	Lab	10	8	C	1 or 2	PL: oral exam, practical achievement, written report, presentation
Research Traineeship	-	-	30	C	3	SL: internship
Master Thesis	-	-	28 2	C	4	PL: thesis SL: presentation

Abbreviations in table:
Type = Type of course; L = Lecture; E = Exercises; S = Seminar; Lab = Laboratory;
C = Compulsory module; E = Elective module;
SL = assessed coursework (´Studienleistung´); PL = exam (‘Prüfungsleistung’)

1.2. Forms of Assessment (Prüfungsleistung PL, Studienleistung SL)

A module is successfully passed, when all corresponding assessments have been successfully accomplished. Modules consist of the following forms of assessments:

Prüfungsleistungen (PL) are written or oral module exams, which test all components of a module. PLs are marked (graded) and contribute to the final mark of the degree as listed in 1.5.

Studienleistungen (SL) are individual achievements, which are accomplished in combination with a corresponding course or lecture. Passing a SL may require solving regular assignments, the regular and successful participation in exercise classes and/or passing a final written or oral exam. SLs are not marked (non-graded) and therefore do not contribute to the final mark.

Successful participation in exercise classes requires at least 50-60% of the points awarded for working on the exercise sheets and 1-2 times presenting solutions in the weekly tutorial. **Regular participation** in the exercises is defined in the examination regulations and requires that no more than 15% of the exercise hours are missed.

1.3. Workload / ECTS-Point System

The *European Credit Transfer and Accumulation System (ECTS)* is a standard for comparing the study attainment and performance of students of higher education across the European Union and other collaborating European countries. It provides more compatibility and mobility between the programmes at different institutions and different countries.

The ECTS credit points (CP), which can be acquired, determine the time requirements for a module with one CP corresponding to a workload of about 30 hours. This workload includes participation in courses, preparation and post-processing of the courses, exercises and exams. The ECTS-System enables the accumulation of credits and marks throughout the entire studies and facilitates documenting the study progress.

1.4. Contents of Modules

Advanced Experimental Physics (9 ECTS)

Within this elective module students may select an advanced lecture on Experimental Physics. Eligible lectures are listed in section 3.1 and in the course catalogue for the current semester.

Advanced Theoretical Physics (9 ECTS)

Within this elective module students may select an advanced lecture on Theoretical Physics. Eligible lectures are listed in section 3.2 and in the course catalogue for the current semester.

Applied Physics (18 ECTS)

Within this elective module students may select various Applied Physics courses. Eligible courses are listed in section 3.3 and in the course catalogue for the current semester. The final module exam (PL) covers the content of lectures with a total of at least 9 ECTS credits (a single course or a combination of courses).

Elective Subjects (10 ECTS)

All 10 ECTS credits of this module can be acquired by selecting different courses by the student’s own choice. The selected courses have to be at the Master’s level, i.e. from the M.Sc. program in Applied Physics and/or other master programs. The examination committee may permit other courses on request. Note that for courses at other faculties different application modalities and requirements may apply. Students are responsible to prove successful participation, so that the examination office of physics can transfer the credits.

Term Paper (6 ECTS)

Within the elective module Term Paper students chose a seminar on a specific topic, with several seminars offered each term.

Master Laboratory Applied Physics (8 ECTS)

In the Master Laboratory Applied Physics students accomplish various lab experiments with a total workload of 8 ECTS credit points. All experiments should be accomplished within the first two semesters. Successful completion of the Master Laboratory Applied Physics is prerequisite for beginning the Research Traineeship.

Research Traineeship (30 ECTS)

Before working on their Master Thesis students engage in a Research Traineeship, which is accomplished within a six-month period. The goal is to acquire preliminary knowledge in a certain research topic in preparation for the final master thesis. For their traineeship and thesis students select a supervisor at the Institute of Physics or at the associated faculties and research institutes. Admission to the Research Traineeship requires successful accomplishment of the module *Master Laboratory Applied Physics* and three of the four marked courses in the modules *Advanced Experimental Physics, Advanced Theoretical Physics, Applied Physics* and *Term Paper*.

Master Thesis (30 ECTS)

In the final six-months Master Thesis students perform independent research on a specialized topic in applied physics and prepare a written thesis. Typically, the Master Thesis is accomplished at the same research group as the traineeship. In a period of 2 weeks before to 4 weeks after submitting the Master Thesis, the students present the results of their thesis work in a public presentation.

1.5. Final mark / grade

The individual module marks contribute to the final grade with the following weights:

Module	**weight**
Advanced Experimental Physics	11 %
Advanced Theoretical Physics	11 %
Applied Physics	11 %
Term Paper	7 %
Master Laboratory Applied Physics	10 %
Master Thesis	50 %

2. Organisation of studies

2.1. Study plan

In the first year, the master students consolidate their knowledge in various compulsory and elective modules. For the first and second semester, an equally balanced workload is recommended with a total of about 30 ECTS credit points each.

The following schedule represents a suggested study plan and may differ depending on the lectures offered and the student's particular choice.

<table>
<tr><th>FS</th><th colspan="5">Module</th><th>total ECTS</th></tr>
<tr><td>1</td><td>Advanced Experimental Physics
9 ECTS</td><td rowspan="2">Applied Physics
18 ECTS</td><td></td><td>Term Paper
6 ECTS</td><td rowspan="2">Master Laboratory Applied Physics
8 ECTS</td><td>28</td></tr>
<tr><td>2</td><td>Advanced Theoretical Physics
9 ECTS</td><td>Elective Subjects
10 ECTS</td><td></td><td>32</td></tr>
<tr><td>3</td><td colspan="5">Research Traineeship
30 ECTS</td><td>30</td></tr>
<tr><td>4</td><td colspan="5">Master Thesis (Thesis and Presentation)
30 ECTS</td><td>30</td></tr>
</table>

2.2. Optional Specialization: Quantum Science and Technology

Within their Master studies, students can specialize in ***Quantum Science and Technology*** by choosing their courses in the modules Advanced Experimental Physics, Advanced Theoretical Physics and Applied Physics accordingly. Students who choose this specialization also need to complete their research phase (Research Traineeship and Master Thesis) in this field. If all requirements are met the specialization will be certified on the final transcript of records.

The following study plan lists the choice of courses required for the specialization:

<table>
<tr><th>FS</th><th colspan="5">Module</th></tr>
<tr><td>1</td><td>Advanced Atomic and Molecular Physics (Exp WiSe)
or
Advanced Condensed Matter I (Exp WiSe)
or
Advanced Optics and Lasers (Exp SoSe)
9 ECTS</td><td rowspan="2">Quantum Hardware* (Exp SoSe)
9 ECTS

and

Advanced Quantum Mechanics (Theo WiSe)
or
Theoretical Condensed Matter Physics (Theo SoSe)
or
Theoretical Quantum Optics (Theo WiSe)
or
Complex Quantum Systems (Theo SoSe)
9 ECTS</td><td></td><td>Term Paper
6 ECTS</td><td rowspan="2">Master Laboratory Applied Physics
8 ECTS</td></tr>
<tr><td>2</td><td>Quantum Information Theory* (Theo SoSe)
9 ECTS</td><td>Elective Subjects
10 ECTS</td><td></td></tr>
<tr><td>3</td><td colspan="5">Research Traineeship in Quantum Science and Technology*
30 ECTS</td></tr>
<tr><td>4</td><td colspan="5">Master Thesis in Quantum Science and Technology* (Thesis and Presentation)
30 ECTS</td></tr>
</table>

* These components are mandatory

The following courses are recommended but not mandatory for the module Elective Subjects:

- Theory and modeling of materials
- Quantum transport
- Orbital angular momentum of light: theory and applications
- Group theory for Atomic, Molecular and Solid State Physics
- Semiconductor Physics
- Laser-based spectroscopy
- Lectures by EUCOR partners

2.3. Enrolment for lectures and courses

For participation in lectures, a registration is recommended, which is possible via the electronic campus management system HISinOne https://campus.uni-freiburg.de/. In order to take part in the final exam a separate registration is required (see below).

2.4. Registration for exams (SL or PL)

In order to finish a module all exercises and exams contained in the module (Studienleistungen SL and Prüfungsleistungen PL) have to be passed. For participating in the exams, a registration via the electronic campus management system HISinOne https://campus.uni-freiburg.de/ is necessary.

The common registration period typically starts with the beginning of the semester end ends one week before the first exam. Within this period registration to and deregistration from an exam is possible. Details on the registration period for each semester and other modalities can be found on the webpage of the examination office www.physik.uni-freiburg.de/studium/pruefungen.

2.5. Resitting exams

Failed examinations may be repeated twice in the modules *Advanced Experimental Physics, Advanced Theoretical Physics and Applied Physics*, and once in the modules *Term Paper, Master Laboratory Applied Physics*, and *Master Thesis*. It is not possible to resit passed examinations to improve the marks.

3. List of Modules and Description

3.1. Advanced Experimental Physics (9 ECTS)

Module 07LE33K-ADV_EXP	**Advanced Experimental Physics**					**9 ECTS**
Responsibility	Dean of Studies, Lecturers for Experimental Physics					
Courses		**Type**	**Credit hrs**	**ECTS**	**Assessment**	**Semester**
	Advanced Experimental Physics	L	4	9	PL: written or oral exam	WiSe + SoSe
	Advanced Experimental Physics	E	2		SL: exercises	WiSe + SoSe
	Total:		**4+2**	**9**		
Required academic assessment	The final module exam (PL) is a written exam (duration: 60-180 minutes) or oral exam (duration: 30 minutes). The course achievement (SL) is the regular and successful participation in the exercises.					
Grading	The grade of the final exam is the final grade of the module.					
Qualification objectives	• Students obtain advanced knowledge in a particular field of experimental physics. • Students are familiar with current problems and research topics in particular fields of modern research in experimental physics. • Students know advanced tools and methods in particular fields. • Specific qualification objectives are listed in the individual course descriptions.					
Course content	A range of advanced lectures is offered on a regular or irregular basis. The specific content of each lecture is detailed in the individual course descriptions. In addition, lectures on specialized physics topics may be offered on an irregular basis and are indicated in the course catalogue as Advanced Experimental Physics lectures.					
Workload (hours)	**Course**	**Type**	**Contact hrs**	**Self-studies**	**Total**	
	Advanced Experimental Physics	L	60 h	180 h	270 h	
	Advanced Experimental Physics	E	30 h	180 h	270 h	
	Total:			**180 h**	**270 h**	
Usability	M.Sc. Applied Physics					

Previous knowledge	Specific prerequisites are given in the individual course descriptions.
Language	English

List of eligible lectures (Module: Advanced Experimental Physics):

Module No.	Lecture Course	ECTS	Term		
			WiSe	SoSe	irregu-lar
07LE33M-ADV_EXP_AMO	Advanced Atomic and Molecular Physics	9	X		
07LE33M-ADV_EXP_OL	Advanced Optics and Lasers	9		X	
07LE33M-ADV_EXP_CM1	Condensed Matter I: Solid State Physics	9	X		
07LE33M-ADV_EXP_CM2	Condensed Matter II: Interfaces and Nanostructures	9		X	
07LE33M-ADV_EXP_PDET	Particle Detectors	9	X		
07LE33M-ADV_EXP_QHW	Quantum Hardware	9		X	

3.1.1. Advanced Atomic and Molecular Physics (9 ECTS)

<table>
<tr><th>Module no.
07LE33M-ADV_EXP_AMO</th><th colspan="4">Advanced Atomic and Molecular Physics</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Lecturers from Experimental Atomic, Molecular and Optical Physics</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Examination</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4+2</td><td>9</td><td>PL: written or oral exam</td></tr>
<tr><td>Term</td><td colspan="4">In general, the course will be offered each winter term.</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">Students have a deeper understanding of both the properties of matter based on the nature and interactions of atoms and molecules, and of current and future technologies based on controlled quantum processes, such as those employed in atomic clocks, atom interferometers, quantum optics and quantum computing, nanoscale engineering, photochemistry and energy conversion.</td></tr>
<tr><td>Course content</td><td colspan="4">• Light-matter interaction: scattering, absorption and emission of light, dressed states, coherence, strong fields
• Scattering of atomic and molecular systems
• Properties of diatomic molecules: vibrations and rotations
• Properties of polyatomic molecules: electronic states, molecular symmetries, chemical bonds
• Modern AMO applications in science and technology</td></tr>
<tr><td>Previous knowledge</td><td colspan="4">Experimental Physics I-IV (B.Sc. Physik)</td></tr>
<tr><td rowspan="2">Workload (hours)</td><td>Course</td><td>Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>90 h</td><td>180 h</td><td>270 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Physics modules: Advanced Physics 1 or 2 (PL), Advanced Physics 3 (SL) or Elective Subjects (SL),
M.Sc. Applied Physics modules: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)</td></tr>
<tr><td>Language</td><td colspan="4">English</td></tr>
</table>

3.1.2. Advanced Optics and Lasers (9 ECTS)

Module no. 07LE33M-ADV_EXP_OL	**Advanced Optics and Lasers**			
Lecturer/s	Lecturers from Experimental Atomic, Molecular and Optical Physics			
Course details	**Type**	**Credit hrs**	**ECTS**	**Examination**
	Lecture and exercises (L+E)	4+2	9	PL: written or oral exam
Term	In general, the course will be offered each winter term.			
Qualification objectives	• Students are familiar with the physical concepts of lasers and know the fundamentals of the interaction between laser light and matter. • Students are able to describe in detail the inherent behaviour and functionality of the many different types of modern lasers. • Students have a deep understanding of the properties of coherent laser light and are able to understand and analyse nonlinear optical effects, e.g. those induced by lasers in transparent materials. • Students are familiar with types of lasers, and the applications of lasers			
Course content	• Light-matter interaction: Absorption/emission, line broadening • Coherence & interference: temporal, spatial coherence, interferometers • The laser principle: 2, 3, 4-level lasers, rate equation models, output power of a laser; • Optical resonators: transmission spectra, stability • Laser modes: Paraxial approximation, Gaussian beams, longitudinal and transverse modes, mode selection • Short laser pulses: Dynamic solutions of rate equation, Q-switching, mode locking, intense short pulses, generation of ultra-short laser pulses • Types of lasers and laser applications • Nonlinear optics: Second, third order polarizability, frequency conversion, optical parametric amplification, high-harmonics generation			
Previous knowledge	Experimental Physics I-IV (B.Sc. Physik)			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Physics modules: Advanced Physics 1 or 2 (PL), Advanced Physics 3 (SL) or Elective Subjects (SL), M.Sc. Applied Physics modules: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.1.3. Condensed Matter I: Solid State Physics (9 ECTS)

<table>
<tr><th>Module no.
07LE33M-ADV_EXP_CM1</th><th colspan="4">Condensed Matter I:
Solid State Physics</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Lecturers from Experimental Condensed Matter and Applied Physics</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Examination</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4+2</td><td>9</td><td>PL: written or oral exam</td></tr>
<tr><td>Term</td><td colspan="4">In general, the course will be offered each winter term.</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">• Students know the reciprocal space description of crystals and related quasi-particles like phonons
• Students know the quantum mechanical description of electrons in periodic potentials (Bloch- and Wannier-functions)
• Students have a good overview of experimental state of the art techniques for the study of the properties of solid-state materials
• Students know how to obtain and are able to interpret experimental data like measurements of electronic band structures or phonon dispersion curves
• Students know about newer developments in the experimental characterization of many-body quantum effects like magnetism or superconductivity</td></tr>
<tr><td>Course content</td><td colspan="4">• Atomic structure of matter
• lattice dynamics, phonons
• electronic structure of materials
• optical properties
• magnetism/superconductivity</td></tr>
<tr><td>Previous knowledge</td><td colspan="4">Experimental Physics I-IV (B.Sc. Physik)</td></tr>
<tr><td rowspan="2">Workload (hours)</td><td>Course</td><td>Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>90 h</td><td>180 h</td><td>270 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Physics modules: Advanced Physics 1 or 2 (PL), Advanced Physics 3 (SL) or Elective Subjects (SL),
M.Sc. Applied Physics modules: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)</td></tr>
<tr><td>Language</td><td colspan="4">English</td></tr>
</table>

3.1.4. Condensed Matter II: Interfaces and Nanostructures (9 ECTS)

<table>
<tr><th>Module no.
07LE33M-ADV_EXP_CM2</th><th colspan="4">Condensed Matter II:
Interfaces and Nanostructures</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Lecturers from Experimental Condensed Matter and Applied Physics</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Examination</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4+2</td><td>9</td><td>PL: written or oral exam</td></tr>
<tr><td>Term</td><td colspan="4">In general the course will be offered each summer term.</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">Students are able to describe interaction forces at interfaces in terms of their range and their consequences on thermodynamic and kinetic properties.
Students understand processes at surfaces like adsorption/desorption, surface re-construction, surface transport, or wettability.
Students are able to describe processes as well as structural transitions at liquid, solid-liquid, and solid interfaces with respect to their hydrodynamic and electronic properties.
Students know processes for preparing well defined and patterned surfaces.
Students identify the relevant processes for the formation of nanostructures and structuring of surfaces at the nm-scale.</td></tr>
<tr><td>Course content</td><td colspan="4">Surfaces and interface
structure formation on surfaces
self-assembly, morphology and transitions
optical and electronic properties</td></tr>
<tr><td>Previous knowledge</td><td colspan="4">Experimental Physics I-IV (B.Sc. Physik)</td></tr>
<tr><td rowspan="2">Workload (hours)</td><td>Course</td><td>Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>90 h</td><td>180 h</td><td>270 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Physics modules: Advanced Physics 1 or 2 (PL), Advanced Physics 3 (SL) or Elective Subjects (SL),
M.Sc. Applied Physics modules: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)</td></tr>
<tr><td>Language</td><td colspan="4">English</td></tr>
</table>

3.1.5. Particle Detectors (9 ECTS)

<table>
<tr><th>Module no.
07LE33M-
ADV_EXP_PDET</th><th colspan="4">Particle Detectors</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Lecturers from Experimental Particle Physics</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Examination</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4+2</td><td>9</td><td>PL: written or oral exam</td></tr>
<tr><td>Term</td><td colspan="4">In general, the course will be offered each winter term</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">• Students are able to understand the physics of particle detection
• Students are able to understand the interaction of particles with matter
• Students are able to understand the different types of particle detectors
• Students are able to design a particle detector for specific experiments</td></tr>
<tr><td>Course content</td><td colspan="4">• Interaction of particles with matter
• General properties of particle detectors
• Tracking detectors
• Time measurement
• Energy measurement
• Particle identification
• Electronics, trigger and data acquisition
• Detector systems in Particle and Astroparticle Physics
• Applications of particle detectors in medicine</td></tr>
<tr><td>Previous knowledge</td><td colspan="4">Experimental Physics V (Nuclear and Particle physics) (B.Sc. Physics)
Experimental Physics IV (Atoms, Molecules, Solid State Physics) (BSc. Physics)</td></tr>
<tr><td rowspan="2">Workload (hours)</td><td>Course</td><td>Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>90 h</td><td>180 h</td><td>270 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Physics modules: Advanced Physics 1 or 2 (PL), Advanced Physics 3 (SL) or Elective Subjects (SL),
M.Sc. Applied Physics modules: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)</td></tr>
<tr><td>Language</td><td colspan="4">English</td></tr>
</table>

3.1.6. Quantum Hardware (9 ECTS)

Module no. 07LE33M-ADV_EXP_QHW	**Quantum Hardware**			
Lecturer/s	Lecturers from Experimental Atomic, Molecular and Optical Physics			
Course details	**Type**	**Credit hrs**	**ECTS**	**Examination**
	Lecture and exercises (L+E)	4+2	9	PL: written or oral exam
Term	In general, the course will be offered each summer term			
Qualification objectives	• Students are familiar with the main concept behind the experimental setups based on quantum interactions. They are familiar with the concept of scalability of quantum systems and decoherence. • Students have a deep understanding of the peculiarities of and differences between the quantum platforms • Students are familiar with different kinds of technologies used for the implementation of quantum simulations.			
Course content	• Introduction (qubit concept; entanglement) • Quantum platforms: photons, cold atoms, ions, spins, SQUID • Quantum sensing • Potential applications: quantum computing; quantum simulations; cryptography			
Previous knowledge	Experimental Physics I-IV (B.Sc. Physik)			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Physics modules: Advanced Physics 1 or 2 (PL), Advanced Physics 3 (SL) or Elective Subjects (SL), M.Sc. Applied Physics modules: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.2. Advanced Theoretical Physics (9 ECTS)

<table>
<tr><th>Module
07LE33K-ADV_THEO</th><th colspan="6">Advanced Theoretical Physics   9 ECTS</th></tr>
<tr><td>Responsibility</td><td colspan="6">Dean of Studies,
Lecturers for Theoretical Physics</td></tr>
<tr><td rowspan="4">Courses</td><td></td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td><td>Semester</td></tr>
<tr><td>Advanced Theoretical Physics</td><td>L</td><td>4</td><td>9</td><td>PL: written or oral exam</td><td>WiSe + SoSe</td></tr>
<tr><td>Advanced Theoretical Physics</td><td>E</td><td>2</td><td>9</td><td>SL: exercises</td><td>WiSe + SoSe</td></tr>
<tr><td>Total:</td><td></td><td>4+2</td><td>9</td><td></td><td></td></tr>
<tr><td>Required academic assessment</td><td colspan="6">The final module exam (PL) is a written exam (duration: 60-180 minutes) or oral exam (duration: 30 minutes). The course achievement (SL) is the regular and successful participation in the exercises.</td></tr>
<tr><td>Grading</td><td colspan="6">The grade of the final exam is the final grade of the module.</td></tr>
<tr><td>Qualification objectives</td><td colspan="6">• Students obtain advanced knowledge in a particular field of theoretical physics.
• Students are familiar with current problems and research topics in particular fields of modern research in theoretical physics.
• Students know advanced tools and methods in particular fields.
• Specific qualification objectives for each lecture are listed in individual course descriptions in 3.3.</td></tr>
<tr><td>Course content</td><td colspan="6">A range of advanced courses is offered on a regular or irregular basis. The specific content of each lecture is detailed in the individual course descriptions.</td></tr>
<tr><td rowspan="4">Workload (hours)</td><td>Course</td><td>Type</td><td colspan="2">Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Advanced Theoretical Physics</td><td>L</td><td colspan="2">60 h</td><td>180 h</td><td>270 h</td></tr>
<tr><td>Advanced Theoretical Physics</td><td>E</td><td colspan="2">30 h</td><td>180 h</td><td>270 h</td></tr>
<tr><td>Total:</td><td></td><td colspan="2"></td><td>180 h</td><td>270 h</td></tr>
<tr><td>Usability</td><td colspan="6">M.Sc. Applied Physics</td></tr>
<tr><td>Previous knowledge</td><td colspan="6">Specific prerequisites are given in the individual course descriptions.</td></tr>
<tr><td>Language</td><td colspan="6">English</td></tr>
</table>

List of eligible lectures (Module: Advanced Theoretical Physics):

Module No.	Lecture	ECTS	Term		
			WiSe	SoSe	irregu-lar
07LE33M-ADV_THEO_QM	Advanced Quantum Mechanics	10	X		
07LE33M-ADV_THEO_CM	Theoretical Condensed Matter Physics	9		X	
07LE33M-ADV_THEO_CS	Classical Complex Systems	9	X		
07LE33M-ADV_THEO_CQS	Complex Quantum Systems	9			X
07LE33M-ADV_THEO_QO	Theoretical Quantum Optics	9	X		
07LE33M-ADV_THEO_QIT	Quantum Information Theory	9		X	
07LE33M-ADV_THEO_COMP	Computational Physics: Materials Science	9		X	

3.2.1. Advanced Quantum Mechanics (10 ECTS)

Module no. 07LE33M-AQM	**Advanced Quantum Mechanics**					
Lecturer/s	Lecturers for Theoretical Physics					
Course details		**Type**	**Credit hrs**	**ECTS**	**Assessment**	**Semester**
	Advanced Quantum Mechanics	L	4	10	PL: written exam	WiSe
	Advanced Quantum Mechanics	E	3		SL: exercises	WiSe
Term	The course will be offered each winter term.					
Qualification objectives	• Students know the foundations of scattering theory and are able to apply these to problems involving simple potentials. • Students know the representations of the rotational group and their relevance for quantum theory. They have basic knowledge in group theory and representation theory in general. They know the meaning of product representations and irreducible representations. They are able to apply Clebsch-Gordon coefficients to simple problems involving angular momentum and spin in atomic spectra. • Students know the connection between spin and statistics. They are able to symmetrize respectively anti-symmetrize multi-particle states. They can describe the Hartree and Hartree-Fock methods and apply them to simple multi-particle systems. • Students know the fundamentals of time-dependent perturbation theory and can apply them to specific time-dependent problems. Students know Dirac's equation and can solve it for the free case.					
Course content	• Scattering theory: scattering amplitude and cross-section, partial wave expansion, Lippmann-Schwinger equation and Born series. • Fundamentals of the representation theory of groups, in particular of the rotation group SO(3). Tensor product representations and irreducible representations. Wigner-Eckart theorem. Applications to angular momentum and spin couplings in atomic, molecular and condensed matter physics. • Time-dependent perturbation theory: Dyson-expansion, Fermi's Golden Rule, examples of application to important time-dependent quantum processes. • Many-particle systems: identical particles, spin-statistic theorem, variational principles, Hartree and Hartree-Fock approximations. • Interaction between radiation and matter. Quantization of the electromagnetic field. Interaction Hamiltonian, emission and absorption. • Relativistic quantum mechanics and quantum field theory; Dirac equation, quantization of Klein-Gordon and Dirac's equation.					
Previous knowledge	Contents of lectures Theoretical Physics I-IV (B.Sc. Physics)					

Workload (hours)	Course	Contact hrs	Self-studies	Total
	Lecture and exercises (L+E)	105 h	195 h	300 h
Usability	M.Sc. Physics modules: Advanced Physics 1 or 2 (PL), Advanced Physics 3 (SL) or Elective Subjects (SL), M.Sc. Applied Physics modules: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.2.2. Theoretical Condensed Matter Physics (9 ECTS)

Module no. 07LE33M-ADV_THEO_CONDMAT	**Theoretical Condensed Matter Physics**			
Lecturer/s	Lecturers from Theoretical Condensed Matter and Applied Physics			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L+E)	4+2	9	PL: written or oral exam
Term	In general, the course will be offered each summer term.			
Qualification objectives	• Students are familiar with the relevant theoretical concepts in Condensed Matter Physics. • Students are able to calculate physical properties of various condensed matter systems based on quantum mechanics, and appreciate the physical ideas behind these approximation schemes, as well as their limitations.			
Course content	• Crystal structures, crystal vibrations, quantization of harmonically coupled lattices, phonons. • Electrons in periodic potentials, Bloch waves, band structure. Application to conductors, insulators and semi-conductors. • Electron phonon coupling. BCS theory of superconductivity. • Spin degrees of freedom. Classical and quantum spin chains.			
Previous knowledge	Experimental Physics I-IV, Theoretical Physics I-IV (B.Sc. Physik)			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Physics modules: Advanced Physics 1 or 2 (PL), Advanced Physics 3 (SL) or Elective Subjects (SL), M.Sc. Applied Physics modules: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.2.3. Classical Complex Systems (9 ECTS)

<table>
<tr><td>Module no.
07LE33M-ADV_THEO_CS</td><td colspan="4">Classical Complex Systems</td></tr>
<tr><td>Lecturer/s</td><td colspan="4">Lecturers from Theoretical Atomic, Molecular and Optical Sciences
or from Theoretical Condensed Matter and Applied Physics</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4+2</td><td>9</td><td>PL: written or oral exam</td></tr>
<tr><td>Term</td><td colspan="4">In general the course will be offered each winter term.</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">• Students are familiar with stochastic and deterministic concepts to model complex systems.
• Students are capable of recognizing and rigorously describing phenomena commonly encountered in complex systems.
• Students are able to use probabilistic notions to model systems subject to uncertainty about their microscopic states and laws.
• Students are able to run and interpret Monte Carlo computer simulations as well as to quantify the confidence in results produced by randomized algorithms.
• Students are able to use basic statistical tools to infer probabilistic statements from empirical observations.</td></tr>
<tr><td>Course content</td><td colspan="4">The first two thirds of the lecture cover basic theory, while the final third is concerned with concrete applications. Topics treated in the latter part depend more strongly on the lecturer.

Stochastic Processes:
• Random walks, Markov model
• Stochastic differential equations and master equations (Langevin- and Fokker-Planck Equation)
• Numerical treatment and Monte Carlo techniques

Non-Linear Dynamics / Chaos Theory:
• Dynamical systems (discrete, differential equations, Hamiltonian)
• Lyapunov exponents
• Attractors and bifurcations

Applications:

Molecular dynamics simulations
• Molecular driving forces and force field models
• Simulation techniques and sampling
• Energy landscapes and analysis of dynamics

Time series analysis and inverse problems
• Estimation and test theory
• Spectral analysis
• State space model</td></tr>
</table>

Previous knowledge	Theoretical Physics I-V			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Physics modules: Advanced Physics 1 or 2 (PL), Advanced Physics 3 (SL) or Elective Subjects (SL), M.Sc. Applied Physics modules: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.2.4. Complex Quantum Systems (9 ECTS)

<table>
<tr><th>Module no.
07LE33M-
ADV_THEO_CQS</th><th colspan="4">Complex Quantum Systems</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Lecturers from Theoretical Atomic, Molecular and Optical Sciences
or from Theoretical Condensed Matter and Applied Physics</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4+2</td><td>9</td><td>PL: written or oral exam</td></tr>
<tr><td>Term</td><td colspan="4">Lecture is offered on an irregular basis.</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">• The students know the advanced physical concepts and mathematical techniques in the field of complex and open quantum systems;
• They have the ability to apply these concepts and techniques to the theoretical modelling and analysis of specific complex systems and to derive emergent phenomena in open systems (e.g. macroscopic classicality) from microscopic laws of quantum mechanics (e.g. decoherence).
• For structural track: The students know how to reason about counter-intuitive aspects of quantum theory using mathematically rigorous notions.</td></tr>
<tr><td>Course content</td><td colspan="4">• Quantum states: Pure and mixed states, density matrices, quantum state space
• Composite quantum systems: Tensor product, entangled states, partial trace and reduced density matrix, quantum entropy
• Open quantum systems: Closed and open systems, dynamical maps, quantum operations, complete positivity and Kraus representation
• Dynamical semigroups and quantum master equations: Semigroups and generators, quantum Markovian master equations, Lindblad theorem
• General properties of the master equation: Dynamics of populations and coherences, Pauli master equation, relaxation to equilibrium
• Decoherence: Destruction of quantum coherence through interaction with an environment, decoherence versus relaxation

Applied Track:
• Microscopic theory: System-reservoir models, Born-Markov approximation, microscopic derivation of the master equation.
• Applications: Quantum theory of the laser, superradiance, quantum transport, quantum Boltzmann equation

Structural Track:
• Uncertainty relations: Joint measurability, uncertainty relations for continuous and discrete observables, information-disturbance trade-off
• Contextuality: Non-Locality, Bell's Theorem, Marginals</td></tr>
<tr><td>Previous knowledge</td><td colspan="4">Theoretical Physics IV (Quantum Mechanics, B.Sc. Physik) and
Advanced Quantum Mechanics (M.Sc. Physics)</td></tr>
</table>

Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Physics modules: Advanced Physics 1 or 2 (PL), Advanced Physics 3 (SL) or Elective Subjects (SL), M.Sc. Applied Physics modules: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.2.5. Theoretical Quantum Optics (9 ECTS)

Module no. 07LE33M-ADV_THEO_QO	**Theoretical Quantum Optics**			
Lecturer/s	Lecturers from Theoretical Atomic, Molecular and Optical Physics			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L+E)	4+2	9	PL: written or oral exam
Term	In general the course will be offered each winter term.			
Qualification objectives	• Students can characterize the quantum state of the electromagnetic field • Students are able to interpret the dynamics of the quantized field in terms of canonically conjugate variables • Students are able to distinguish classical from quantum features of the quantized field, and to perform the classical limit • Students are able to infer the quantum state of the light field from multi-point correlation functions • Students are able to describe the quantum state of strongly coupled light-matter systems • Students can give a semiclassical description of light-matter systems • Students are familiar with a selection of paradigmatic experimental settings to probe generic quantum properties of the light field			
Course content	• Quantization of the radiation field • Coherent states • Phase space representation of quantum states • Counting statistics • Dressed states • Floquet theory • Special topics, e.g. micromaser theory, elements of entanglement theory, laser theory, master equations, coherent control • Light-matter interaction			
Previous knowledge	Experimental Physics I-IV, Theoretical Physics I-IV			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Physics modules: Advanced Physics 1 or 2 (PL), Advanced Physics 3 (SL) or Elective Subjects (SL), M.Sc. Applied Physics modules: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.2.6. Quantum Information Theory (9 ECTS)

<table>
<tr><th>Module no.
07LE33M-
ADV_THEO_QIT</th><th colspan="4">Quantum Information Theory</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Lecturers from Theoretical Atomic, Molecular and Optical Physics</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4+2</td><td>9</td><td>PL: written or oral exam</td></tr>
<tr><td>Term</td><td colspan="4">In general the course will be offered each summer term.</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">• Students are familiar with the main concepts of quantum information theory.
• Students are familiar with the main differences between classical and quantum computing.</td></tr>
<tr><td>Course content</td><td colspan="4">Certain information processing tasks can be performed more efficiently with quantum mechanical systems than with classical ones. Famous examples are Shor's quantum algorithm for factoring large integer numbers and quantum cryptography enabling secure communication between two parties. In this lecture, we will introduce fundamental concepts of quantum information theory (e.g. entangled states and quantum correlations) and discuss possible applications such as quantum teleportation or quantum computing.

1. Foundations of quantum information theory
(Quantum state space, qubits, composite systems, tensor product, correlations and entanglement, quantum entropies)

2. Quantum cryptography
(Quantum key distribution, BB84 protocol)

3. Quantum computation
(Quantum gates, quantum circuit model, universal quantum gates, quantum algorithms: Shor, Grover)

4. Physical realizations
(Trapped ions, cavities, NMR, squids, spintronics)

5. Quantum error correction
(Quantum noise, quantum operations, quantum error correction, fault-tolerant quantum computation)</td></tr>
<tr><td>Previous knowledge</td><td colspan="4">Theoretical Physics I-IV (B.Sc. Physik)</td></tr>
<tr><td rowspan="2">Workload (hours)</td><td>Course</td><td>Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>90 h</td><td>180 h</td><td>270 h</td></tr>
</table>

Usability	M.Sc. Physics modules: Advanced Physics 1 or 2 (PL), Advanced Physics 3 (SL) or Elective Subjects (SL), M.Sc. Applied Physics modules: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)
Language	English

3.2.7. Computational Physics: Materials Science (9 ECTS)

<table>
<tr><th>Module no.
07LE33M-
ADV_THEO_COMPPHYS</th><th colspan="4">Computational Physics: Materials Science</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Lecturers from Computational Physics</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4+2</td><td>9</td><td>PL: written or oral exam</td></tr>
<tr><td>Term</td><td colspan="4">The lecture is offered regularly in the summer term.</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">• Students have understood the basic Hamiltonian of CMS
• Students are familiar with the various approximations that lead to different methods in CMS: Born-Oppenheimer approximation, classical approximation for the nuclei, local density approximation, tight-binding, semi-empirical interatomic potentials, coarse grained models, hydrodynamic limit
• Students have a basic knowledge of density functional theory.
• Students can set up simple molecular dynamics calculations.
• Students are familiar with the different types of Born-Oppenheimer surfaces for the different types of interatomic binding.
• Students are familiar with extended molecular dynamics methods.</td></tr>
<tr><td>Course content</td><td colspan="4">This lecture provides an introduction into basic concepts of atomistic computational materials science. The computational tools for different time and length scales will be introduced and it will be discussed how these tools can be combined in order to solve physical problems extending over too many scales for one single method alone. We will start with a brief introduction to density functional theory and more approximate methods such as tight binding. Quantum derived forces can be extracted from these methods and the short term dynamics of small nanosystems can be studied. For the simulation of larger systems and longer time scales, classical interatomic potentials are required. The students will become familiar with some examples for the different types of interatomic potentials: e.g. Lennard-Jones, Born-Mayer, Embedded-Atom, Bond-Order-potentials as well as bead-spring potentials for polymers. A brief introduction into the basic methodology of micro-canonical and thermostated molecular dynamics simulations will be given.
The lecture is accompanied by a hands-on programming course. Classical molecular dynamics simulations will be used to study metallic and covalently bonded materials.</td></tr>
<tr><td>Previous knowledge</td><td colspan="4">Basic knowledge in classical and quantum mechanics</td></tr>
<tr><td rowspan="2">Workload (hours)</td><td>Course</td><td>Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>90 h</td><td>180 h</td><td>270 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Physics modules: Advanced Physics 1 or 2 (PL), Advanced Physics 3 (SL) or Elective Subjects (SL),</td></tr>
</table>

	M.Sc. Applied Physics modules: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)
Language	English

3.3. Applied Physics (18 ECTS)

<table>
<tr><td>Module
07LE33K-APHYS</td><td colspan="6">Applied Physics — 18 ECTS</td></tr>
<tr><td>Responsibility</td><td colspan="6">Dean of Studies,
Lecturers of the Institute of Physics and associated Institutes</td></tr>
<tr><td rowspan="3">Courses</td><td></td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td><td>Semester</td></tr>
<tr><td>Applied Physics lectures by own choice</td><td>L+E</td><td>According to selected courses</td><td>18</td><td>SL: written or oral exam (9 ECTS)
PL: written or oral exam (9 ECTS)</td><td>WiSe + SoSe</td></tr>
<tr><td>Total:</td><td></td><td></td><td>18</td><td></td><td></td></tr>
<tr><td>Organization</td><td colspan="6">Students select different lectures in order collect at least 18 ECTS credits in total from the list of Applied Physics lectures given below.</td></tr>
<tr><td>Required academic assessment</td><td colspan="6">For the graded assessment (PL), students select lectures containing at least 9 ECTS credit points, where they attend written (duration: 60-180 minutes) or oral exams (duration: 30 minutes).
The course achievements (SL) are written (duration: 60-180 minutes) or oral exams (duration: 30 minutes) and the regular and successful participation in the exercises.</td></tr>
<tr><td>Grading</td><td colspan="6">The final grade of the module is the ECTS-weighted mean of the grades of the graded exams (PL).</td></tr>
<tr><td>Qualification objectives</td><td colspan="6">The qualification objects are subject to the selected course and are listed in the individual course descriptions.</td></tr>
<tr><td>Course content</td><td colspan="6">A range of Applied Physics lectures is offered on a regular or irregular basis. The specific content of each lecture is detailed in the individual course descriptions.</td></tr>
<tr><td rowspan="3">Workload (hours)</td><td colspan="2">Course</td><td colspan="2">Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td colspan="2">Applied Physics lectures</td><td colspan="3">subject to selected lectures</td><td>540 h</td></tr>
<tr><td colspan="2">Total:</td><td colspan="3"></td><td>540 h</td></tr>
<tr><td>Usability</td><td colspan="6">M.Sc. Applied Physics</td></tr>
<tr><td>Previous knowledge</td><td colspan="6">Specific prerequisites are given in the individual course descriptions.</td></tr>
<tr><td>Language</td><td colspan="6">English</td></tr>
</table>

List of eligible lectures (Module: Applied Physics):

Module no.	Lecture	ECTS	Term		
			WiSe	SoSe	irregu-lar
Optical Technologies:					
07LE33M-MOIF	Physics of Microscopy and Image Formation	7	X		
07LE33M-NANOOPT	Nano-Photonics - Optical manipulation and particle dynamics	7		X	
11LE50MO-5221SL	Wave Optics	7		X	
07LE33M-LSPEC	Laser-based Spectroscopy and Analytical Methods	5		X	
07LE33M-PHOTOVOLT	Photovoltaic Energy Conversion	5		X	
11LE68MO-4103	Multi-junction solar cell technology and concentrator photovolatic	3	X		
Physics in Life Science & Medical Physics:					
07LE33M- BI-OPHYS	Biophysik – Grundlagen und Konzepte	7	X		
07LE33M-DYNBIO	Dynamic Systems in Biology	7			X
07LE33M-MOLDYN	Molecular Dynamics & Spectroscopy	7			X
07LE33M-NANOBIO	Physics of Nano-Biosystems	5		X	
07LE33M-PHYSMED	Physics of Medical Imaging Methods	5	X		
07LE33M-CARDI	Biophysics of cardiac function and signals	5	X		
07LE33M-Neuro	Computational Neuroscience: Models of Neurons and Networks	7		X	
07LE33M-Neuro	Computational Neuroscience: Simulation of Biological Neuronal Networks	5		X	
Interactive and Adaptive Materials:					
07LE33M-POL	Polymer Physics	9	X		
07LE33M-SELFAS	Physical Processes of Self-Assembly and Pattern Formation	7			X
07LE33M-HL	Fundamentals of Semiconductors & Optoelectronics	5	X		
07LE33M-HLBAU	Semiconductor Devices	5		X	
11LE50V-5115	Mechanical Properties and Degradation Mechanisms	3		X	
07LE33M-MODMAT	Theory and Modeling of Materials	5	X	X	
07LE33M-QTRANS	Quantum Transport	7			X

Course No.	Lecture	ECTS	Term		
			WiSe	SoSe	irregu-lar
Applied Physics Methods:					
07LE33M-LTPHYS	Low Temperature Physics	9			X
07LE33M-STATNUM	Statistics and Numerics	7			X
07LE33M-COMPPHYS	Computational Physics: Density Functional Theory	7			X
11LE50MO-2080	Modeling and System Identification	6	X		

3.3.1. Microscopy and Optical Image Formation (7 ECTS)

<table>
<tr><th>Module no.
07LE33M-MOIF</th><th colspan="4">Physics of microscopy and image formation</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Prof. Dr. Alexander Rohrbach</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>3+2</td><td>7</td><td>SL or PL</td></tr>
<tr><td>Term</td><td colspan="4">The lecture is offered in the winter term</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">The student should learn how to guide light through optical systems, how optical information can be described very advantageously by three-dimensional transfer functions in Fourier space, how phase information can be transformed to amplitude information to generate image contrast. Furthermore, one should learn that wave diffraction is does not reduce the information and how to circumvent the optical resolution limit. The student should learn to distinguish between coherent and incoherent imaging, learn about modern techniques using self-reconstructing laser beams, two photon excitation, fluorophores depletion through stimulated emission (STED) or multi-wave mixing by coherent anti-Stokes Raman scattering (CPLS).
The tutorials help the student to get a more in depth and thorough under-standing of the lecture. Here, a special focus is put on the transfer of knowledge obtained in the lecture. To achieve this, the students should pre-pare weekly exercise and present them during the tutorial. Only difficult exercises are presented by the tutors.</td></tr>
<tr><td>Course content</td><td colspan="4">The scientific breakthroughs and technological developments in optical microscopy and imaging have experienced a real revolution over the last 10-15 years. Hence, the 2014 Nobel-Prize for super-resolution microscopy could be seen as a logical consequence. This lecture gives an overview about physical principles and techniques used in modern photonic imaging.

Topics:
1. Microscopy: History, Presence and Future
2. Wave- and Fourier-Optics
3. Three-dimensional optical imaging and information transfer
4. Contrast enhancement by Fourier-filtering
5. Fluorescence – Basics and techniques
6. Point scanning and confocal microscopy
7. Microscopy with self-reconstructing beams
8. Optical tomography
9. Nearfield and Evanescent Field Microscopy
10. Super-resolution using structured illumination
11. Multi-Photon-Microscopy
12. Super resolution imaging by switching single molecules

The lecture has an ongoing emphasis on applications, but nevertheless presents a mixture of fundamental physics, compact mathematical descriptions and many examples and illustrations. The lecture aims to encompass the current state of a scientific field, which will influence the fields of nanotechnology and biology/medicine quite significantly.</td></tr>
</table>

Literature	Optical Microscopy: • Jerome Mertz: Introduction to Optical Microscopy, Roberts & Co Publ. 2009 • U. Kubitschek, Fluorescence Microscopy, Wiley-Blackwell 2013 • Min Gu, Advanced optical imaging theory, Springer - Berlin, 1999 • James B. Pawley: Handbook of Biological Confocal Microscopy, Springer - Berlin, 2006 • Herbert Gross: Handbook of optical systems, Vol 2: Physical image formation, Wiley VCH 2005 General Optics: • Hecht, E. (2002). Optics, Addison Wesley. • Saleh, B. E. A. and M. C. Teich (1991). Fundamentals of Photonics, Wiley & Sons,Inc. • Herbert Gross: Handbook of optical systems, Vol 1-5			
Preliminaries / Previous knowledge				
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	75 h	135 h	210 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.2. Biophysik - Grundlagen und Konzepte (7 ECTS)

<table>
<tr><td>Module no.
07LE33M-BIOPHYS</td><td colspan="4">Biophysik - Grundlagen und Konzepte</td></tr>
<tr><td>Lecturer/s</td><td colspan="4">Prof. Dr. Alexander Rohrbach</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>3+2</td><td>7</td><td>SL or PL</td></tr>
<tr><td>Term</td><td colspan="4">The lecture is offered in the winter term</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">Die Vorlesung stellt einen Streifzug durch die moderne Zellbiophysik dar, adressiert Fragen der aktuellen Forschung und stellt moderne Untersuchungsmethoden vor. Dies beinhaltet klassische, aber auch neueste physikalische Modelle und Theorien, welche in Kombination mit experimentellen Messmethoden einen erheblichen Fortschritt in der Biophysik, ermöglicht haben.
Die Studierenden sollen lernen, wie Methoden aus der klassischen Mechanik mit denen der statistischen Physik verknüpft werden, um das Verhalten biologischer Strukturen in Zeit und Raum zu verstehen. Dies beinhaltet die Reduktion und Abstraktion komplexer biologischer Probleme, damit diese mathematisch und durch Computersimulationen beschrieben und so durch den Vergleich mit Messungen und Analysemethoden besser verstanden werden können.
Die Vorlesung (3 ECTS) richtet sich an Physiker:innen und Ingenieur:innen im Masterstudium. Der Vorlesungsstoff wird mit wöchentlichen Übungen (zusätzlich 3-4 ECTS) veranschaulicht und gefestigt.</td></tr>
<tr><td>Course content</td><td colspan="4">Die Vorlesung stellt Grundlagen und moderne Konzepte der Biophysik und der Physik der weichen Materie dar. Vielfältiges Anschauungsmaterial wird mit mathematischen Konzepten der statistischen Mechanik vorgestellt - im Ortsraum wie im Frequenzraum.

Inhalte:
1. Aufbau der Zelle oder Das Rezept für biophysikalische Forschung
2. Diffusion und Fluktuationen
3. Mess- und Manipulationstechniken
4. Biologisch relevante Kräfte
5. Biophysik der Proteine
6. Polymerphysik einzelner Filamente
7. Visko-Elastizität und Mikro-Rheologie
8. Die Dynamik des Zytoskeletts
9. Molekulare Motoren
10. Membran-Biophysik
11. Anhang</td></tr>
<tr><td>Literature</td><td colspan="4">• Rob Phillips: Physical Biology of the Cell
• Joe Howard: Mechanics of Motor Proteins and the Cytoskeleton
• Gary Boal: Mechanics of the Cell
• Erich Sackmann & Rudolf Merkel: Lehrbuch der Biophysik</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="4"></td></tr>
</table>

Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	75 h	135 h	210 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	German			

3.3.3. Nano-Photonics - Optical manipulation and particle dynamics (7 ECTS)

Module no. 07LE33M-NANOOPT	**Nano-Photonics -** **Optical manipulation and particle dynamics**			
Lecturer/s	Prof. Dr. Alexander Rohrbach			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L+E)	3+2	7	SL or PL
Term	The lecture is offered in the summer term			
Qualification objectives	Optical traps and optical micro-manipulation techniques do have the potential to play a key role in future micro- and nano-systems in conjunction with the life sciences. In this lecture the students should learn what is doable with optical forces, where physical limits are and what is limited by nowadays technology. Besides fascinating fundamental research various applications related to biology or fluctuation-based systems are pre-sented. The lecture is manifold and teaches basics in optics, statistical physics and biology/biophysics. The tutorials help the students to get a more in depth and thorough under-standing of the lecture. Here, a special focus is put on the transfer of knowledge obtained in the lecture. To achieve this the students should pre-pare weekly exercise and present them during the tutorial.			
Course content	1. Introduction 2. Light - Information carrier and actor 3. About microscopy 4. Light scattering 5. Optical forces 6. Tracking beyond the uncertainty 7. Brownian motion and calibration techniques 8. Photonic force microscopy 9. Applications in cell biophysics 10. Time-multiplexing and holographics optical traps 11. Applications in microsystems technology 12. Applications in nanotechnology			
Literature	General optics: • Hecht, E. (2002). Optics, Addison Wesley. • Saleh, B. E. A. and M. C. Teich (1991). Fundamentals of Photonics, Wiley & Sons, Inc. Nano optics • L. Novotny & B. Hecht, E. (2002). Principles of Optics, Cambridge. Statistical physics and thermodynamics • Standard text books Chemical and biological forces and interactions • Leckband, D. & J. Israelachvili (2001). "Intermolecular forces in biology." Quart. Rev. Biophys 34: 105–267			

Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	75 h	135 h	210 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.4. Wave Optics (7 ECTS)

Module no. 11LE50MO-5221S	**Wave Optics**			
Lecturer/s	Prof. Dr. Alexander Rohrbach			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L+E)	3+2	7	SL or PL
Term	The lecture is offered in the summer term			
Qualification objectives	The goal of this lecture is to teach the students how light interacts with small structures and how optical systems guide light. The students will start at Maxwell's equations and move on to the description of light as photon or wave, depending on the given problem. Furthermore, the close connection between spatial and temporal coherence, interference and holography is demonstrated. The last chapter teaches concepts of linear and non-linear light scattering, as well as the most important plasmonic effects. In total, the students learn how to shape light in three dimensions and how optical problems that arise in research and development are solved.			
Course content	1. Introduction Some motivation, literature and a bit of history 2. From Electromagnetic Theory to Optics What is light? Which illustrative pictures do the Maxwell equations provide? If matter, dielectric and metallic, consists of coupled, damped springs (harmonic oscillators), how does matter depend on the frequency of light? What do the wave equation and the Helmholtz equation express and how can one handle waves in position space and frequency space. 3. Fourier-Optics How does a wave transform position information into directional information? Why can this be well described by Fourier transformations in 1D, 2D and 3D? What has this to do with linear optical system theory including spatial frequency filters and the sampling theorem? 4. Wave-optical Light Propagation and Diffraction Different methods are introduced of how to describe the propagation of ways in position space and frequency space. We do the direct transfer from propagation to diffraction of light and momentum space. We treat evanescent waves, thin diffracted objects, the propagation of light in inhomogeneous media and the diffraction at gratings. This allows to discuss important active elements such as acousto-optic and spatial light modulators. We end with adaptive optics and phase conjugation. 5. Interference, Coherence and Holography We learn how a composition of k-vectors defines the phases of interfering waves and the resulting stripe patterns. The relative phases of each partial wave in space and time change the interference significantly and define the coherence of light - these concepts will be discussed in detail. We learn how to write and read phase information in holography.			

	6. Light Scattering and Plasmonics The interaction of light with matter is based on particle scattering: we discuss the theoretical concepts of light scattering on the background of Fourier theory. We expend these approaches to photon diffusion, nonlinear optics, fluorescence and Raman scattering or scattering at semiconductor quantum dots - which are all hot topics in modern Photonics. A big emphasis is put on the description of surface plasmons and particle plasmons, where light can be extremely confined.			
Literature	Accompanying to the lecture printed lecture notes with defined gaps (white boxes) are distributed.			
Preliminaries / Previous knowledge				
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	75 h	135 h	210 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.5. Laser-based Spectroscopy and Analytical Methods (5 ECTS)

<table>
<tr><th>Module no.
07LE33M-LSPEC</th><th colspan="4">Laser-based Spectroscopy and Analytical Methods</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">PD Dr. Frank Kühnemann (Fraunhofer IPM)</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>2+1</td><td>5</td><td>SL or PL</td></tr>
<tr><td>Term</td><td colspan="4">The lecture is offered in the summer term</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">At the end of the course, the students
• Will have knowledge about laser-based spectroscopic methods, particularly with respect to analytical applications.
• Will understand the physical principles of tuneable laser operation.
• Will be enabled to evaluate the fundamental and practical limitations of detection techniques.
• Will have insight into development processes necessary to transfer a scientific method into a practical tool for industrial environments.
• Will be trained in the preparation and presentation of scientific talks.</td></tr>
<tr><td>Course content</td><td colspan="4">Lasers did become a powerful tool for measurement applications in areas like industry, medicine, or environment. The current course focuses on the use of tuneable lasers to interrogate the spectral “fingerprints” of gases, liquids and solids for analytical purposes. Typical examples are air quality monitoring or process control in industry.

The lecture block in the first half of the course will give a comprehensive introduction into the following topics
• Infrared molecular spectra
• Tuneable lasers
• Spectroscopic techniques (absorption, photoacoustic spectroscopy, cavity-based methods)
• Background signals, noise and detection limits

The seminar talks in the second block will focus on the application of different spectroscopic methods for analytical tasks. At the start of the course, students will choose from a list of provided topics to prepare a talk and a short written summary. The preparation will be supported by topical literature and discussion sessions with the course staff. Duration of the talks will be approximately 30 minutes, followed by a discussion of content and presentation style.</td></tr>
<tr><td>Literature</td><td colspan="4">• lecture script
• recommended literature will be announced in the lecture</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="4">Advanced Optics and Lasers (recommended)</td></tr>
</table>

Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	45 h	105 h	150 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.6. Photovoltaic Energy Conversion (5 ECTS)

<table>
<tr><th>Module no.
07LE33M- PHOTOVOLT</th><th colspan="4">Photovoltaic Energy Conversion</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Dr. Uli Würfel (Fraunhofer ISE)</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>2+1</td><td>5</td><td>SL or PL</td></tr>
<tr><td>Term</td><td colspan="4">The lecture is offered in the summer term</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">• Students have a profound understanding of the working principles of solar cells and are thus able to apply these principles to different kinds of solar cell configurations
• Students are familiar with state-of-the-art solar cells, the processes limiting their conversion efficiency, how these factors can be identified and if they could (in principle) be overcome</td></tr>
<tr><td>Course content</td><td colspan="4">• Fundamentals of semiconductors, intrinsic and extrinsic, Fermi-Dirac statistics, bands
• Generation, recombination and transport of charge carriers
• Lifetime, diffusion length, pn-junction, ideal solar cell
• Real solar cell structures, carrier selectivity & semi-permeable membranes
• Characterisation methods
• Overview about different PV technologies: Si-based, thin film, Organic, Perovskite, Concentrator-PV</td></tr>
<tr><td>Literature</td><td colspan="4">• lecture script
• P. Würfel, Physics of Solar Cells, 2nd edition 2009, Wiley VCH</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="4">Basic knowledge of semiconductor physics is helpful but not mandatory</td></tr>
<tr><td rowspan="2">Workload (hours)</td><td>Course</td><td>Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>45 h</td><td>105 h</td><td>150 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Physics: Elective Subjects (SL),
M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)</td></tr>
<tr><td>Language</td><td colspan="4">English</td></tr>
</table>

3.3.7. Multi-junction solar cell technology and concentrator photovolatic (3 ECTS)

Module no. 11LE68MO-4103	**Multi-junction solar cell technology and concentrator photovolatic**			
Lecturer/s	Prof. Dr. Andreas Bett (Fraunhofer ISE)			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L)	2	3	SL
Term	The lecture is offered in the winter term			
Qualification objectives	• Students have a profound understanding of the concept of of multi-junction solar cells and the underlying physical principles. • Students are familiar with concentrator photovoltaics and characterization & manufacturing of CPV systems			
Course content	• multi-junction solar cell approach to increase the sunlight conversion efficiency, different solar cell architectures • introduction III-V materials, adjustment of band-gap, growth techniques • methods for charaterisation of III-V materials and multi-junction solar cells • PV concentrator technology: low and high concentration • componentes of CPV systems: optics, cells, manufacturing • CPV system analysis including an economical evalution			
Literature	• "Solar Cells and Their Applications", L. Fraas, L.Partain, Wiley, 2010; • "Advanced Concetps in Photovoltaics", AJ Nozik, G. Conibeer, MC Beard, Royal Society of Chemistry, 2014; • "Next Generation Photovoltaics", AB Cristobal Lopez, A. Marti Vega, A. Luque Lopez, Springer Series in Optical Sciences 165, 2012, • "Concentrator Phtovoltaics", A Luque, V. Andreev, Springer Verlag, Series in Optical Sciences, 2011			
Preliminaries / Previous knowledge	-			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L)	30 h	60 h	90 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.8. Dynamic Systems in Biology (7 ECTS)

<table>
<tr><th>Module no.
07LE33M-DYNBIO</th><th colspan="4">Dynamic Systems in Biology</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Prof. Dr. Jens Timmer</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>3+2</td><td>7</td><td>SL or PL</td></tr>
<tr><td>Term</td><td colspan="4">The lecture is offered on an irregular basis</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">• Students are familiar with classical and modern dynamic systems in biology.
• Students are able to mathematically formulate dynamic systems in biology as differential equations and implement these on the computer.</td></tr>
<tr><td>Course content</td><td colspan="4">• Numerical integration of differential equations
• Mathematical biology
• Population models
• Hodgkin-Huxley model
• Turing model
• Enzyme kinetics
• Systems biology
• Metabolism
• Signal transduction
• Gene regulation</td></tr>
<tr><td>Literature</td><td colspan="4">• J.D. Murray. Mathematical Biology, Springer</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="4">Basics of Analysis and Linear Algebra</td></tr>
<tr><td rowspan="2">Workload (hours)</td><td>Course</td><td>Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>75 h</td><td>135 h</td><td>210 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Physics: Elective Subjects (SL),
M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)</td></tr>
<tr><td>Language</td><td colspan="4">English</td></tr>
</table>

3.3.9. Molecular Dynamics & Spectroscopy (7 ECTS)

Module no. 07LE33M- MOLDYN	**Molecular Dynamics & Spectroscopy**			
Lecturer/s	Prof. Dr. Gerhard Stock			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L+E)	3+2	7	SL or PL
Term	The lecture is offered on an irregular basis			
Qualification objectives	• Students have a profound knowledge of theoretical principles underlying the dynamics of molecular systems. • Students are familiar with time-resolved spectroscopic techniques that are able to probe dynamics in molecular systems.			
Course content	• Time-Dependent Quantum Dynamics • Density Matrix Theory • Quantum-Classical Formulation • Linear Spectroscopy • Nonlinear Techniques • Multidimensional Spectroscopy			
Literature	• P. Hamm, M. Zanni, Concepts and Methods of 2D Infrared Spectroscopy, Cambridge University Press, 2011 • V. May, O. Kühn, Charge and Energy Transfer Dynamics in Molecular Systems, Wiley-VCH, 2004 • S. Mukamel, Principles of Nonlinear Optical Spectroscopy, Oxford University Press, 1995			
Preliminaries / Previous knowledge				
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	75 h	135 h	210 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.10. Physics of Nano-Biosystems (5 ECTS)

Module no. 07LE33M-NANOBIO	**Physics of Nano-Biosystems**			
Lecturer/s	Prof. Dr. Thorsten Hugel (Faculty of Chemistry), Dr. Thomas Pfohl			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L)	2+1	5	SL or PL
Term	The lecture is offered regularly in the summer term.			
Qualification objectives	• Students have a profound knowledge of the physical principles that govern biological systems in particular molecular machines. • Students are familiar with the experimental methods to study biological systems in particular molecular machines. • In the tutorials the students gain an in-depth understanding of of the lecture and discuss most recent literature.			
Course content	• Fundamental forces in Nano-Biosystems (elastic, viscous, thermal, chemical, entropic, polymerization) • Concepts of equilibrium and non-equilibrium systems and measurements • Jarzynski equation • Linear and rotational molecular motors • Molecular details of muscle function • Optical and magnetic tweezers, AFM • Single molecule force spectroscopy • Single molecule fluorescence • Concepts of nanotribology and biolubrication			
Literature	• Jonathon Howard: “Mechanics of Motor Proteins and the Cytoskeleton“ (2005) • Phil Nelson: "Biological Physics: Energy, Information, Life" (2003) • Rob Philips, Jane Kondev, Julie Theriot, Hernan Garcia: "Physical Biology of the Cell" (2012) • Recent journal publications			
Previous knowledge	Basic knowledge of statistics and optics is helpful but not mandatory.			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L)	30 h	120 h	150 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.11. Physics of Medical Imaging Methods (5 ECTS)

Module no. 07LE33M-PHYSMED	**Physics of Medical Imaging Methods**			
Lecturer/s	Prof. Dr. Michael Bock (Universitätsklinikum)			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L)	2+1	5	SL or PL
Term	The lecture is offered regularly in the winter term.			
Qualification objectives	• Students are able to distinguish and describe the physical basis of currently applied medical imaging methods • Students will become familiar with recent developments in medical imaging technology and their clinical application			

Course content	Medical imaging is becoming increasingly important in the detection of disease, in the management of the patients, and in the monitoring of a therapy. In this lecture the physical basics of different medical imaging technologies will be presented, and different clinical application scenarios will be discussed. The following topics will be addressed:
	• overview over the physics of medical imaging
	• Magnetic Resonance Imaging (MRI)
	  ○ magnetisation, Bloch equations, relaxation times T1 and T2
	  ○ spin gymnastics and image contrast
	  ○ magnets, gradients and radio-frequency coils
	  ○ quantitative MRI
	  ○ functional MRI, flow, diffusion, perfusion measurements
	• Nuclear Medicine
	  ○ principles of radio-tracer detection
	  ○ scintigraphy
	  ○ single photon emission computed tomography (SPECT)
	  ○ positron emission tomography (PET)
	• ultrasound (US)
	  ○ sound generation and propagation in tissue
	  ○ US imaging
	  ○ Doppler US
	  ○ therapeutic applications of US (Lithotrypsy)
	• X-ray Imaging
	  ○ properties and generation of X-rays
	  ○ fluoroscopy
	  ○ computed tomography
	  ○ image reconstruction from projections
	• role of medical imaging in
	  ○ the detection of disease
	  ○ in patient management
	• therapy monitoring			

Literature	• Oppelt A: Imaging Systems for Medical Diagnostics • Dössel O: Bildgebende Verfahren in der Medizin: Von der Technik zur medizinischen Anwendung			
Preliminaries / Previous knowledge				
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L)	45 h	105 h	150 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.12. Biophysics of Cardiac Function and Signals (5 ECTS)

<table>
<tr><th>Module no.
07LE33M-CARDI</th><th colspan="4">Biophysics of cardiac function and signals</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Dr. Viviane Timmermann, Prof. Dr. Peter Kohl
(Faculty of Medicine, Institute for Experimental Cardiovascular Medicine)</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L)</td><td>2+1</td><td>5</td><td>SL or PL</td></tr>
<tr><td>Term</td><td colspan="4">The lecture is offered regularly in the winter term.</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">The basic concept of this lecture is to examine a biological system, analyse it and define mathematical equations in order to describe the system. In this lecture, the heart is used as this system. The students learn the electrical and mechanical function of the heart and its modelling. Additionally, the bioelectrical signals that are generated in the human body are described and how these signals can be measured, interpreted and processed. The content is explained both on the biological level and based mathematical modelling.</td></tr>
<tr><td>Course content</td><td colspan="4">• Cell membrane and ion channels
• Cellular electrophysiology
• Conduction of action potentials
• Cardiac contraction and electromechanical interactions
• Optogenetics in cardiac cells
• Numerical field calculation in the human body
• Measurement of bioelectrical signals
• Electrocardiography
• Imaging of bioelectrical sources
• Biosignal processing</td></tr>
<tr><td>Literature</td><td colspan="4">• lecture slides</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="4">Basic interest in biology and computational modelling. Knowledge in Matlab or Python are beneficial</td></tr>
<tr><td rowspan="2">Workload (hours)</td><td>Course</td><td>Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L)</td><td>45 h</td><td>105 h</td><td>150 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Physics: Elective Subjects (SL),
M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)</td></tr>
<tr><td>Language</td><td colspan="4">English</td></tr>
</table>

3.3.13. Computational Neuroscience: Models of Neurons and Networks (7 ECTS)

Module no. 07LE33M-Neuro	**Computational Neuroscience: Models of Neurons and Networks**			
Lecturer/s	Prof. Dr. Stefan Rotter (Faculty of Biology, Bernstein Center Freiburg)			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L+E)	2+2	7	SL or PL
Term	The lecture is offered regularly in the summer term.			
Qualification objectives	The students have the competence to • link mathematical models with biological phenomena arising in systems neuroscience both using theory and computer simulations; • understand the fundamental trade-off between biological detail and mathematical abstraction, and evaluate its consequences; • explain the steps necessary to develop and validate models of a biological neuron or a biological neuronal network; • appreciate and explain the gain in understanding biological mechanisms that arise from the study of mathematical models of neuronal systems; • critically discuss the limits of mathematical modeling and numerical methods in computational neuroscience.			
Course content	This lecture series covers important standard topics in computational neuroscience, focusing on dynamic networks of spiking neurons • Mathematical concepts and methods • Hodgkin-Huxley theory of the action potential • Stochastic theory of ionic channels • The integrate-and-fire neuron model • Stochastic point processes • Stochastic theory of synaptic integration • Stochastic theory of spike generation: The perfect integrator • Stochastic theory of spike generation: The leaky integrator • Conductance based neurons and networks • Correlated neuronal populations • Pulse packets and synfire chains • Random graphs and networks • Dynamics of spiking networks • Population dynamics of recurrent networks.			
Literature	• lecture slides • a bibliography and web-links to complementary reading for each course day will be provided along with the slides of the lecture.			
Preliminaries / Previous knowledge	Familiarity with elementary calculus and linear algebra is assumed. Background in basic neurobiology is helpful, but not required.			

Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L)	105 h	105 h	210 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.14. Computational Neuroscience: Simulation of Biological Neuronal Networks (5 ECTS)

Module no. 07LE33M-Neuro	**Computational Neuroscience: Simulation of Biological Neuronal Networks**			
Lecturer/s	Prof. Dr. Stefan Rotter (Faculty of Biology, Bernstein Center Freiburg)			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L+E)	1+2	5	SL or PL
Term	The lecture is offered regularly in the summer term.			
Qualification objectives	• link mathematical models with biological phenomena arising in systems neuroscience, both using theory and computer simulations; • implement and simulate simple neuronal network models using modern tools and methods of scientific programming (based on Python and NEST); • implement simple programs for data analysis and apply them to simulated data; • appreciate and explain the gain in understanding biological mechanisms that arise from the study of mathematical models of neuronal systems and their simulation • critically discuss the limits of mathematical modelling and numerical methods in computational neuroscience.			
Course content	This course covers the fundamentals of simulating networks of single-compartment spiking neuron models. We start from the concept of a point neuron and then introduce more complex topics such as phenomenological models of synaptic plasticity, connectivity patterns and network dynamics.			
Literature	• lecture slides • see also http://www.nest-initiative.org/ for some general information and an online tutorial on the BNN simulator NEST			
Preliminaries / Previous knowledge	Basic knowledge in scientific computing with Python is absolutely required. Self-study is possible, see http://www.python.org/ for some general information and an online tutorial on the programming language Python. Further documentation on the scientific libraries used in the course is also found online (see http://scipy.org/).			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L)	60 h	90 h	150 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.15. Polymer Physics (9 ECTS)

Module no. 07LE33M-POL	**Polymer Physics**			
Lecturer/s	Prof. Dr. Günter Reiter			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L+E)	4+2	9	SL or PL
Term	The lecture is offered in the winter term			
Qualification objectives	• Students get to know fundamental concepts in polymer physics. • They are familiar with experimental techniques for the characterization of polymers.			
Course content	We can't imagine life and technology today without polymers, if you think of materials like PET bottles and PVC, nylon, teflon or rubber. Also in nature biopolymers are ubiquitous, e.g. DNA, proteins or cellulose. This lecture will give an introduction into the experimental and theoretical concepts in understanding and characterisation of polymer systems. Both, applied and material aspects will be discussed - like polymer flow, elastomers and crystalline polymers - as well as present topics of fundamental research, e.g. glass transition, dynamics in confined geometries and self assembly. The lecture will deal with basic theoretical concepts and descriptive experiments. It will start with simple single chain phenomena and step by step develop more complex structures and dynamics of polymer solutions, melts and blends.			
Literature	• G. Strobl, The Physics of Polymers • Colby & Rubinstein, Polymer Physics			
Preliminaries / Previous knowledge	Experimental Physics I-IV (B.Sc. Physik), Thermodynamics			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Physics: Advanced Physics 2 (PL), Advanced Physics 3 (SL), Elective Subjects (SL), M.Sc. Applied Physics: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.16. Physical Processes of Self-Assembly and Pattern Formation (7 ECTS)

Module no. 07LE33M-SELFAS	**Physical Processes of Self-Assembly and Pattern Formation**			
Lecturer/s	Prof. Dr. Günter Reiter			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L+E)	3+2	7	SL or PL
Term	The lecture is offered on an irregular basis			
Qualification objectives	Students will learn how structural organization, i.e., the increase in internal order of a system, can lead to regular patterns on scales ranging from molecular to the macro-scopic sizes. They will understand the physics of how molecules or objects put them-selves together without guidance or management from an outside source.			
Course content	Goal: Questions about how organization and order in various systems arises have been raised since ancient times. Self-assembling processes are common throughout nature and technology. The ability of molecules and objects to self-assemble into supra-mo-lecular arrangements is an important issue in nanotechnology. The limited number of forms and shapes we identify in the objects around us represent only a small sub-set of those theoretically possible. So why don't we see more variety? To be able answering such a question we have to learn more about the physical processes responsible for self-organization and self-assembly. Preliminary program: “Physical laws for making compromises” Self-assembly is governed by (intermolecular) interactions between pre-existing parts or disordered components of a system. The final (desired) structure is 'encoded' in the shape and properties of the basic building blocks. In this course, we will discuss general rules about growth and evolution of structures and patterns as well as methods that predict changes in organization due to changes made to the underlying components and/or the environment.			
Literature	• Yoon S. LEE, Self-Assembly and Nanotechnology: A Force Balance Approach, Wiley 2008 • Robert KELSALL, Ian W. HAMLEY, Mark GEOGHEGAN, Nanoscale Science and Technology, Wiley, 2005 • Richard A.L. JONES, Soft Machines: Nanotechnology and Life, Oxford University Press, USA 2008 • Philip BALL, Shapes, Flow, Branches. Nature's Patterns: A Tapestry in Three Parts, Oxford University Press, USA • J.N. ISRAELACHVILI, Intermolecular and Surface Forces, Third Edition, Elsevier, 2011 • Continuative and supplementary references will be given during the lecture.			
Preliminaries / Previous knowledge	Experimentalphysik IV (Condensed Matter)			

Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	75 h	135 h	210 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.17. Fundamentals of Semiconductors & Optoelectronics (5 ECTS)

<table>
<tr><th>Module no.
07LE33M- HL</th><th colspan="4">Fundamentals of Semiconductors & Optoelectronics</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">apl. Prof. Dr. Joachim Wagner, Prof. Andreas Bett (Fraunhofer ISE)</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>2+1</td><td>5</td><td>SL or PL</td></tr>
<tr><td>Term</td><td colspan="4">The lecture is offered in the winter term</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">• Students become familiar with fundamental concepts of semiconductor physics as well as techniques for the fabrication of bulk semiconductor materials and epitaxial semiconductor layers; furthermore, they gain knowledge in experimental techniques for the characterization of semiconductors as well as for determining band structure parameters.
• Students become also familiar with the working principle and different variants of key optoelectronic devices.</td></tr>
<tr><td>Course content</td><td colspan="4">• Inorganic crystalline semiconductor materials (such as Si and GaAs)
• Fabrication of bulk semiconductor crystals and epitaxial layers
• Electronic band structure, tight-binding vs. nearly free electron approach
• Effective mass of electrons and holes, n- and p-type doping
• Density of states, statistics of electrons and holes
• Electrical transport by electrons and holes, electric fields and currents
• Quantization effects in semiconductors, quantum films and superlattices
• p-n-junction, photodiode, light emitting diode (LED), diode laser</td></tr>
<tr><td>Literature</td><td colspan="4">• H. Ibach, H. Lüth, „Festkörperphysik" (Springer, 2009)
• K. Seeger, „Semiconductor Physics“ (Springer, 2004)
• P. Yu, M. Cardona, „Fundamentals of Semiconductors“ (Springer, 2010)</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="4">Solid-state physics and theoretical physics at the level of a BSc in Physics</td></tr>
<tr><td rowspan="2">Workload (hours)</td><td>Course</td><td>Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>45 h</td><td>105 h</td><td>150 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Physics: Elective Subjects (SL),
M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)</td></tr>
<tr><td>Language</td><td colspan="4">English or German</td></tr>
</table>

3.3.18. Semiconductor Devices (5 ECTS)

Module no. 07LE33M- HLBAU	**Semiconductor Devices**			
Lecturer/s	apl. Prof. Dr. Harald Schneider (Helmholtz-Zentrum Dresden-Rossendorf HZDR)			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L+E)	2+1	5	SL or PL
Term	The lecture is offered in the summer semester as a block course during the Pentecost break (May/June)			
Qualification objectives	• Students are familiar with fundamental concepts of semiconductor physics. • They know the principle of basic and advanced semiconductor devices.			
Course content	• Transport phenomena • Metal-semiconductor-contact, Schottky-Diode • p-n junction: diode rectifier, photodiode, LED, laserdiode, solar cell • Bipolar transistors, HBT • Field effect-transistors: JFET, MESFET, HEMT, MOSFET, FGFET • Quantum structure-elements: RTD, QWIP, QCL, ICL			
Literature	• S.M. Sze and K.K. Ng, Physics of Semiconductor Devices, Wiley, 2006 • S.M. Sze, Semiconductor Devices, Wiley, 2001			
Preliminaries / Previous knowledge	Experimentalphysik IV (Solid state physics), lecture „Fundamentals of Semiconductors & Optoelectronics" (apl. Prof. J. Wagner)			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	45 h	105 h	150 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.19. Mechanical Properties and Degradation Mechanisms (3 ECTS)

Module no. 11LE50MO-5115	**Mechanical Properties and Degradation Mechanisms**			
Lecturer/s	Prof. Dr. Chris Eberl (Fraunhofer IWM)			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L)	2	3	SL
Term	The lecture is offered in the summer term			
Qualification objectives	The goal is to learn how materials properties and their impact on functionality and performance of micro systems. You will learn about the physical mechanisms in structural and functional materials as well as damage evolution during the applications lifetime. Based on the physical understanding you can evaluate microsystem designs, improve their lifetime and performance. This allows specifying materials and systems closer to their performance limit.			

Course content	• Introduction: physical mechanisms
	• Fundamentals in stress and strain as well as anisotropic properties
	• Fundamentals in mechanics of beams and membranes explained in examples
	• Micro- and nanostructured materials in micro systems
	• Small scale characterization of mechanical properties
	  ○ Intrinsic stresses
	  ○ Elastic and plastic behavior
	  ○ Adhesion properties
	• Principles and loading conditions in functional materials for actors & sensors.			

Literature	• M. Ohring: „The Materials Science of Thin Films“, Academic Press, 1992 • L.B. Freund and S. Suresh: „Thin Film Materials“ • T.H. Courtney: „Mechanical Behaviour of Materials“, Mc-Graw-Hill, 1990 • M. Madou: “Fundamentals of Microfabrication“, CRC Press 1997 • W. Menz und P. Bley: „Mikrosystemtechnik für Ingenieure“, VCH Publishers, 1993 • Chang Liu: Foundations of MEMS, Illinois ECE Series, 2006			
Previous knowledge	-			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L)	30 h	60 h	90 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.20. Theory and Modeling of Materials (5 ECTS)

Module no. 07LE33M- MODMAT	**Theory and Modeling of Materials**			
Lecturer/s	apl. Prof. Dr. Christian Elsässer (Fraunhofer IWM)			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L+E)	2+1	5	SL or PL
Term	Courses of the lecture series are offered regularly in alternating order.			
Qualification objectives	• Students become able to develop and apply theoretical models to investigate practical problems of the physics of materials • Students become familiar with theoretical condensed-matter physics and computational modeling and simulation of materials			
Course content	The series of one- or two-semester elective-subject lectures introduces theoretical models and computational methods of solid-state physics for the description of many-electron systems, by means of which cohesion and structure, physical, chemical, or mechanical properties of perfect crystals and real materials can be understood qualitatively and calculated quantitatively on a microscopic fundament. The lecture series comprises courses on, e.g., these topics: • Electronic-structure theory of condensed matter I + II • Superconductivity I (phenomenology) + II (microscopic theory) • Theoretical models for magnetic properties of materials • Theory of atomistic and electronic structures at interfaces in crystals • etc. The content of each course will be announced for each semester.			
Literature	recommended literature will be announced in each lecture			
Preliminaries / Previous knowledge	Theoretical physics and solid-state physics on the level of a BSc in Physics			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	45 h	105 h	150 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.3.21. Quantum Transport (7 ECTS)

<table>
<tr><td>Module no.
07LE33M- QTRANS</td><td colspan="4">Quantum Transport</td></tr>
<tr><td>Lecturer/s</td><td colspan="4">PD Dr. Michael Walter</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>3+2</td><td>7</td><td>SL or PL</td></tr>
<tr><td>Term</td><td colspan="4">The lecture is offered irregularly in the summer term.</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">• Students become familiar with advanced theoretical tools relevant for quantum transport theory (Green functions, scattering theory, diagrammatic methods for performing disorder average, Landau-Büttiker formalism)
• Students understand how quantum effects modify the transport behaviour in various physical systems</td></tr>
<tr><td>Course content</td><td colspan="4">How to describe transport of a particle from one point in space to another one is a fundamental problem in theoretical physics, which is at the same time highly relevant for many technological applications, for example in electronics (transport of electrons) or solar cells (separation of positive and negative charge carriers generated by light). On microscopic scales, quantum properties -- such as the wave nature of a quantum particle, or the quantization of energy levels -- become relevant and make quantum transport different from classical transport based on Newton's equations. In this lecture, we will approach the topic of quantum transport from different perspectives, with focus on (i) transport of quantum particles (or waves) in disordered structures which are described in a statistical way, and (ii) the explicit description of transport in an electronic device at the atomic scale, with the single molecule transistor as prominent example, which is likely to be the basis of future electronics.</td></tr>
<tr><td>Literature</td><td colspan="4">• E. Akkermans and G. Montambaux, Mesoscopic Physics of electrons and photons (Cambridge University Press, Cambridge, 2007)
• P. Sheng, Introduction to Wave Scattering, Localization, and Mesoscopic Phenomena (Academic Press, New York, 1995)
• S. Datta, Quantum Transport: Atom to Transistor (Cambridge, 2005).</td></tr>
<tr><td>Previous knowledge</td><td colspan="4">Basic quantum mechanics</td></tr>
<tr><td rowspan="2">Workload (hours)</td><td>Course</td><td>Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>75 h</td><td>135 h</td><td>210 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Physics: Elective Subjects (SL),
M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)</td></tr>
<tr><td>Language</td><td colspan="4">English</td></tr>
</table>

3.3.22. Low Temperature Physics (9 ECTS)

Module no. 07LE33M- LTPHYS	**Low Temperature Physics**			
Lecturer/s	Prof. Dr. Frank Stienkemeier			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L+E)	4+2	9	SL or PL
Term	The lecture is offered on an irregular basis			
Qualification objectives	• The lecture Low Temperature Physics provides an introduction to the physical principles as well as the experimental techniques for working at low temperatures and reaching extreme low temperature conditions. • Students will be familiar with material properties at low temperatures. • Students will know how low temperatures are generated, how cryostats are designed, and what materials are used. • Students will learn modern scientific work at low as well as ultra-low temperatures			
Course content	• Temperature-dependent material properties (Phase diagrams and physical states, thermal expansion, friction, viscosity, thermal conductivity, electrical conductivity) • Superfluidity • Matrix and helium droplet isolation techniques • Superconductivity • Generation of low temperatures (refrigerators, Joule-Thompson effect, cryo-coolers) • Measurements at low temperature conditions (temperature, pressure, levels of liquids, magnetic measurements, acoustic measurements, etc.) • Cryostats (thermal insulation, materials, containers and transfer lines, etc.) • Cold dilute samples (cold molecular beams, trapped molecules and trapped ions) • Ultra-cold temperatures			
Literature	• Enss, Hunklinger, Tieftemperaturphysik, Springer (2000) • Frank Pobell, Matter and Methods at Low Temperatures, Springer (1996) • J.G. Weisend II, Handbook of Cryogenic Engineering, Taylor & Francis (1998)			
Preliminaries / Previous knowledge	Experimental Physics I-IV Quantum Mechanics			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h

Usability	M.Sc. Physics: Advanced Physics 2 (PL), Advanced Physics 3 (SL), Elective Subjects (SL), M.Sc. Applied Physics: Advanced Experimental Physics (PL), Applied Physics (PL or SL) or Elective Subjects (SL)
Language	English

3.3.23. Statistics and Numerics (7 ECTS)

Module no. 07LE33M-STATNUM	**Statistics and Numerics**			
Lecturer/s	Prof. Dr. Jens Timmer			
Course details	**Type**	**Credit hrs**	**ECTS**	**Assessment**
	Lecture and exercises (L+E)	3+2	7	SL or PL
Term	The lecture is offered on an irregular basis			
Qualification objectives	• Students are familiar with the basic concepts of statistical reasoning. • Students are able to mathematically formulate statistical and numerical problems. • Students can implement computer programs to solve statistical and numerical problems.			
Course content	• Random variables • Parameter estimation • Test theory • Solution of systems of linear equations • Optimization • Non-linear modeling • Kernel estimator • Integration of ordinary, partial and stochastic differential equations • Spectral analysis • Markov Chain Monte Carlo procedures			
Literature	• Press et al. Numerical Recipes, Cambridge University Press			
Preliminaries / Previous knowledge	Basics of Analysis and Linear Algebra			
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	75 h	135 h	210 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English or German			

3.3.24. Computational Physics: Density Functional Theory (7 ECTS)

<table>
<tr><th>Module no.
07LE33M-DFT</th><th colspan="4">Computational Physics: Density Functional Theory</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Prof. Dr. Michael Moseler</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>3+2</td><td>7</td><td>SL or PL</td></tr>
<tr><td>Term</td><td colspan="4">The lecture is offered on an irregular basis</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">• Students are familiar with electronic structure calculations.
• Students are familiar with the basic Hamiltonian of the electronic structure problem and electronic many-body wave function.
• Students know the Hartree-Fock equations and post Hartree-Fock methods – such as Møller-Plesset and Configurational Interaction.
• Students are familiar with the Hohenberg-Kohn-theorem, the Kohn-Sham-equations, the concept of an exchange-correlation potential and the various local approximations to it.
• Student arefamiliar with time-dependent DFT and know the Runge-Gross-theorem and the time-dependent Kohn-Sham-equations.</td></tr>
<tr><td>Course content</td><td colspan="4">Density functional theory (DFT) has become one of the most important tools for the numerical solution of the electronic many-body Schrödinger equation. It is currently used by many material scientists to study the properties complex systems containing up to several thousand atoms and electrons. This lecture introduces the theoretical foundations of DFT within the Hohenberg-Kohn-Sham frame work. It also touches numerical questions in an accompanying hands-on course. Numerical exercises will cover the electronic structure of atoms and nanoparticles.</td></tr>
<tr><td>Literature</td><td colspan="4">Lecture script: Electronic structure of matter</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="4">Basic knowledge in many-body quantum mechanics</td></tr>
<tr><td rowspan="2">Workload (hours)</td><td>Course</td><td>Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>75 h</td><td>135 h</td><td>210 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Physics: Elective Subjects (SL),
M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)</td></tr>
<tr><td>Language</td><td colspan="4">English</td></tr>
</table>

3.3.25. Modelling and System Identification (6 ECTS)

<table>
<tr><th>Module no.
11LE50MO-2080</th><th colspan="4">Modelling and System Identification</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Prof. Dr. Moritz Diehl (IMTEK)</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>2+2</td><td>6</td><td>SL or PL</td></tr>
<tr><td>Term</td><td colspan="4">The lecture is offered regularly in the winter semester.</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">Aim of the module is to enable the students to create and identify models that help to describe and predict the behaviour of dynamic systems. In particular, students shall become able to use input-output measurement data in form of time series to identify unknown system parameters and to assess the validity and accuracy of the obtained models.</td></tr>
<tr><td>Course content</td><td colspan="4">Linear and Nonlinear Least Squares, Maximum Likelihood and Bayesian Estimation, Cramer-Rao-Inequality, Recursive Estimation, Dynamic System Model Classes (Linear and Nonlinear, Continuous and Discrete Time, State Space and Input Output, White Box and Black Box Models), Application of identification methods to several case studies. The lecture course will also review necessary concepts from the three fields Statistics, Optimization, and Systems Theory, where needed.</td></tr>
<tr><td>Literature</td><td colspan="4">• Lecture manuscript
• Ljung, L. (1999). System Identification: Theory for the User. Prentice Hall
• Lecture manuscript "System Identification"</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="4">Differential Equations, Systems Theory and Feedback Control</td></tr>
<tr><td rowspan="2">Workload (hours)</td><td>Course</td><td>Contact hrs</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>60 h</td><td>120 h</td><td>180 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Physics: Elective Subjects (SL),
M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)</td></tr>
<tr><td>Language</td><td colspan="4">English</td></tr>
</table>

3.4. Elective Subjects (10 ECTS)

<table>
<tr><th>Module
07LE33K-ELSUB_APHYS</th><th>Elective Subjects 10 ECTS</th></tr>
<tr><td>Responsibility</td><td>Dean of Studies,
or Faculty/Institute responsible for selected course</td></tr>
<tr><td>Courses</td><td>
<table>
<tr><th></th><th>Type</th><th>Credit hrs</th><th>ECTS</th><th>Assess-ment</th><th>Semester</th></tr>
<tr><td>Advanced Physics or Applied Physics or Mathematics lectures or courses from other M.Sc./M.A. programs by own choice</td><td>L+E</td><td>According to selected courses</td><td>10</td><td>SL: written or oral exam</td><td>WiSe + SoSe</td></tr>
<tr><td>Total:</td><td></td><td></td><td>10</td><td></td><td></td></tr>
</table>
</td></tr>
<tr><td>Required academic assessment</td><td>The course achievements (SL) are written (duration: 60-180 minutes) or oral exams (duration: 30 minutes) and the regular and successful participation in the exercises.</td></tr>
<tr><td>Grading</td><td>unmarked</td></tr>
<tr><td>Qualification objectives</td><td>The qualification objects are subject to the selected course.</td></tr>
<tr><td>Course content</td><td>Students select different courses by own choice in order collect at least 10 ECTS credit points in total. The selection may contain lectures of the M.Sc. Applied Physics program, or of the M.Sc./M.A. programs of other disciplines. The examination committee may admit courses of other external programs upon application. The course content is subject to the selected course.</td></tr>
<tr><td>Workload (hours)</td><td>
<table>
<tr><th>Course</th><th>Contact hrs</th><th>Self-studies</th><th>Total</th></tr>
<tr><td>Elective courses</td><td colspan="2">subject to selected courses</td><td>300 h</td></tr>
<tr><td>Total:</td><td colspan="2"></td><td>300 h</td></tr>
</table>
</td></tr>
<tr><td>Usability</td><td>M.Sc. Applied Physics</td></tr>
<tr><td>Previous knowledge</td><td>Subject to selected courses</td></tr>
<tr><td>Language</td><td>Subject to selected courses</td></tr>
</table>

3.5. Term Paper (6 ECTS)

Module 07LE33M-TP	**Term Paper**					**6 ECTS**
Responsibility	Dean of Studies, Lecturers of the Institute of Physics					
Courses		**Type**	**Credit hrs**	**ECTS**	**Assessment**	**Semester**
	Term paper seminar	S	2	6	PL: oral presentation and written report	WiSe + SoSe
	Total:		**2**	**6**		
Required academic assessment	The final module exam (PL) is an oral presentation to a specialized physics topic or an adjacent area (duration 30-45 minutes) and a written report. Active participation in all presentations of the seminar is expected.					
Grading	The final grade is the arithmetic mean of the grades for the oral presentation and the written report.					
Qualification objectives	• Students are able to handle scientific literature and to search in scientific publications • Students are able to prepare and present a topic of current physical research in front of a broad audience • Participants have the skills to lead a discussion in a group of students • Students can give scientific lecture and are able to incorporate didactical elements					
Course content	The research groups of the Institute of Physics offer various seminars each term. Allocation and registration to a particular seminar will be in a common event generally held in the first week of the semester. The *Term Paper* seminar comprises approximately 10 presentations from a coherent field of physics or a neighbouring scientific area.					
Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**		
	Term paper seminar	21 h	159 h	180 h		
	Total:	**21 h**	**159 h**	**240 h**		
Usability	M.Sc. Physics, M.Sc. Applied Physics					
Previous knowledge	Basic knowledge in respective topic as acquired in self-studies or lecture					
Language	English					

3.6. Master Laboratory Applied Physics (8 ECTS)

Module 07LE33M-MLAB_APHYS	**Master Laboratory Applied Physics**					**8 ECTS**
Responsibility	Head of the master laboratory					
Courses	**Course**	**Type**		**ECTS**	**Assessment**	**Semester**
	Master Laboratory Applied Physics	Lab	-	8	PL: experi-mental work, written report, oral presentation	WiSe + SoSe
	Total:			**8**		
Organisation	The Master Laboratory Applied Physics consists of the successful accomplishment of different laboratory experiments. In total, all experiments comprise an on-site workload of 16 full days (with 2 days corresponding to 1 ECTS credit point).					
Required academic assessment	For each experiment, the students have to prepare the scientific background, which is tested in an initial written and/or oral exam, perform the experiment and collect their data, and prepare a written lab report. For some experiments, an oral presentation of their results is requested.					
Grading	For each of the experiments a grade is given based on an initial written and oral questioning (test of the preparatory knowledge), the experimental performance and the written report (incl. lab report and analysis). All marks contribute equally to the final module grade (arithmetic mean).					
Repetition	If individual experiments have to be repeated a date has to be arranged with the respective supervisor of the experiment.					
Qualification objectives	• Students are able to perform complex advanced experiments running over several days • Students are able to apply advanced statistical data analysis methods • Students are able to prepare a written lab report • Students are able to critically evaluate and assess their experimental results					
Course content	The current catalogue of laboratory experiments is available online on http://www.physik.uni-freiburg.de/studium/labore					

Workload (hours)	**Course**	**Contact hrs**	**Self-studies**	**Total**
	Master Laboratory Applied Physics	120 h (16 days*7.5 h)	120 h	240 h
	Total:	**150 h**	**90 h**	**240 h**

Usability	M.Sc. Applied Physics
Previous knowledge	- Experimental skills as acquired e.g. in the Physics Laboratory B (B.Sc. Physik) - Statistical methods of data analysis
Language	English

3.7. Research Traineeship (30 ECTS)

Module 07LE33M-RTRAIN	**Research Traineeship**			**30 ECTS**
Responsibility / Supervision	Dean of Studies, Group leaders at the Institute of Physics and associated Institutes			
Course details	**Type**		**ECTS**	**Assessment**
	Research (under supervision)	6 months	30	SL
Organisation	Prior to their master's thesis students engage in a Research Traineeship which is accomplished in a six-month period. The aim of this module is to acquire basic knowledge in a certain research topic and field in preparation for the subsequent Master Thesis. For the traineeship, students select a supervisor at the Institute of Physics or at one of the associated and participating research institutes. The research traineeship can be started at any time and has a duration of exactly 6 months. The students have to register for the research traineeship at the examination office.			
Grading	ungraded			
Qualification objectives	• Students have specialized basic knowledge in a certain research topic. • Students know and are able to apply specific experimental and/or theoretical tools and methods in a specialised field of research. • Students are prepared for performing a self-dependent research project (preparation for Master Thesis)			
Course content	• Students acquire basic knowledge in a certain field of research in preparation for their Master Thesis. • Participants obtain training in applying experimental and/or theoretical tools in a specialized field of research. • Students participate in a current research project under the supervision of lecturers and researchers (post-docs and doctoral researchers).			
Workload (hours)	900 h distributed over a six-month period			
Usability	M.Sc. Physics, M.Sc Applied Physics			
Precondition	Admission to the Research Traineeship requires successful accomplishment of the module *Master Laboratory* and of three of the four marked courses (AR) of the modules *Advanced Quantum Mechanics*, *Advanced Physics 1*, *Advanced Physics 2*, and *Term Paper*.			
Language	English			

3.8. Master Thesis (30 ECTS)

<table>
<tr><th>Module
07LE33M-MSC</th><th colspan="3">Master Thesis</th><th>30 ECTS</th></tr>
<tr><td>Responsibility / Supervision</td><td colspan="4">Group leaders at the Institute of Physics and associated Institutes</td></tr>
<tr><td rowspan="4">Module details</td><td>Type</td><td></td><td>ECTS</td><td>Assessment</td></tr>
<tr><td>Master Thesis</td><td>6 months</td><td>28</td><td>PL: final thesis</td></tr>
<tr><td>Master Colloquium</td><td>45 min</td><td>2</td><td>SL: oral presentation</td></tr>
<tr><td>Total:</td><td></td><td>30</td><td></td></tr>
<tr><td>Organisation</td><td colspan="4">For their master thesis students select a supervisor at the Institute of Physics or at one of the associated and participating research institutes. Typically, the master thesis is pursued within the same work group as the traineeship. The Master Thesis starts at the latest 2 weeks after successful completion of the Research Traineeship. Registration has to be arranged with the examination office.</td></tr>
<tr><td>Grading</td><td colspan="4">The final thesis is graded by two examiners. One examiner is the supervisor of the thesis. Both grades contribute equally to the final grade (arithmetic mean).</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">• Students acquired specialized knowledge of a certain research topic and field.
• Students have strong expertise in applying specific experimental and/or theoretical tools and methods in their field of research.
• Students are able to perform independent research and can critically evaluate and assess their scientific results.
• Students can search and read scientific literature and apply and relate reported results to their research.</td></tr>
<tr><td>Module content</td><td colspan="4">• Acquiring in-depth knowledge in the field of the master thesis work.
• Working on a particular problem in a specialized field of research.
• Development of the required experimental and/or theoretical tools and methods.
• Preparation of a written report on the performed research work.
• Preparation and performance of an oral presentation in the form of a public colloquium, discussing the topic of the master thesis, its physical context, and the underlying physical concepts.</td></tr>
<tr><td>Workload (hours)</td><td colspan="4">900 h distributed over a six-month period. This workload includes research, preparation of the written thesis and preparation of the final presentation.</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Physics, M.Sc Applied Physics</td></tr>
<tr><td>Precondition</td><td colspan="4">Admission to the Master Thesis requires successful accomplishment of the module Research Traineeship.</td></tr>
<tr><td>Language</td><td colspan="4">English or German</td></tr>
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