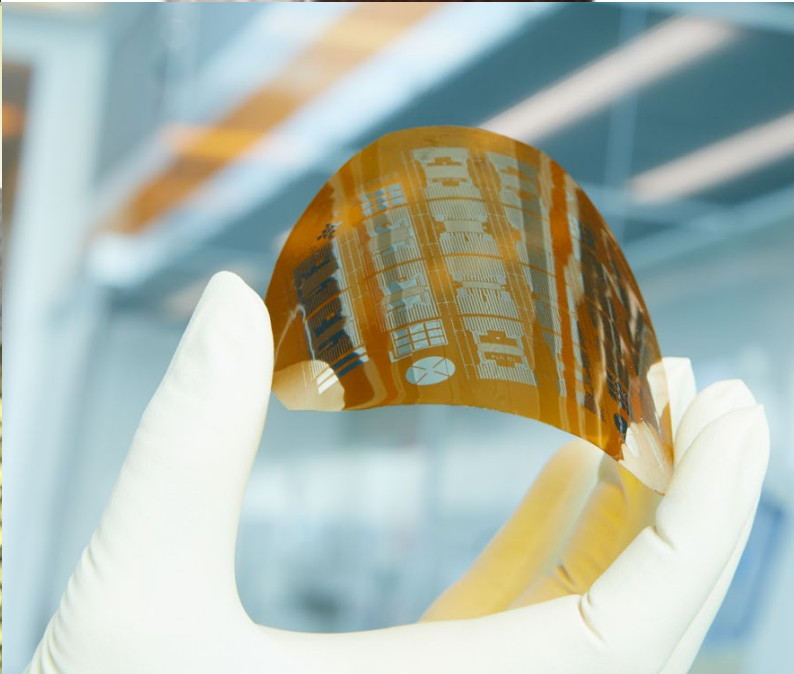
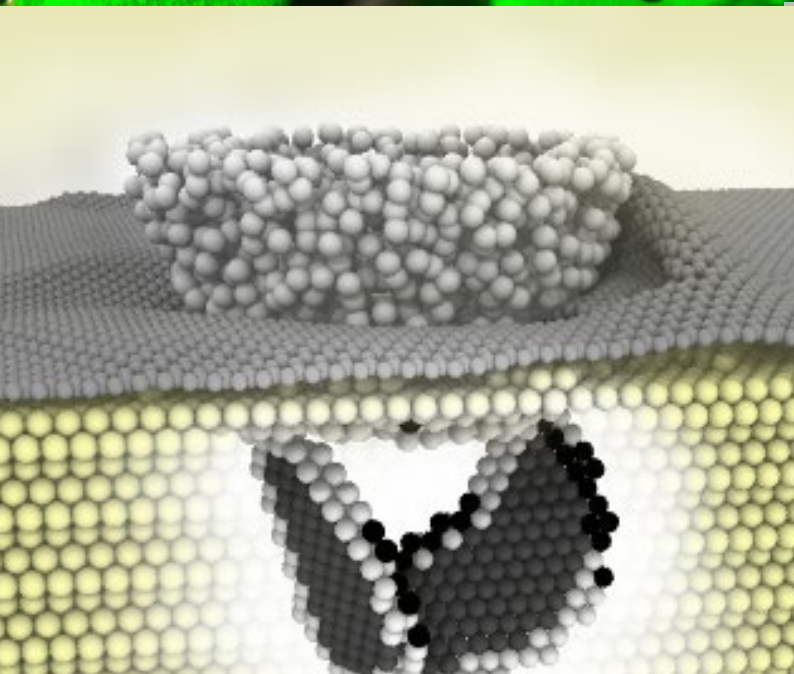
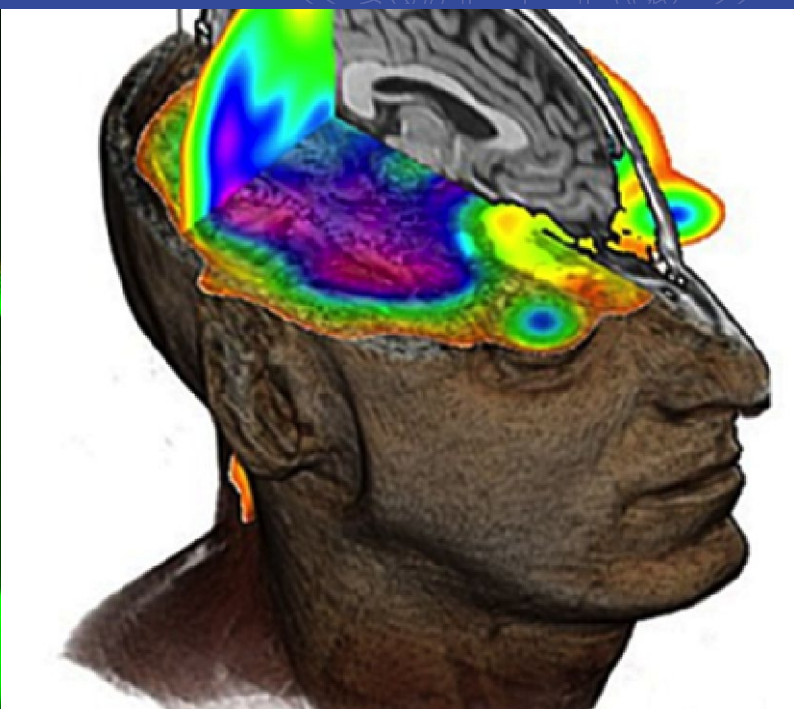
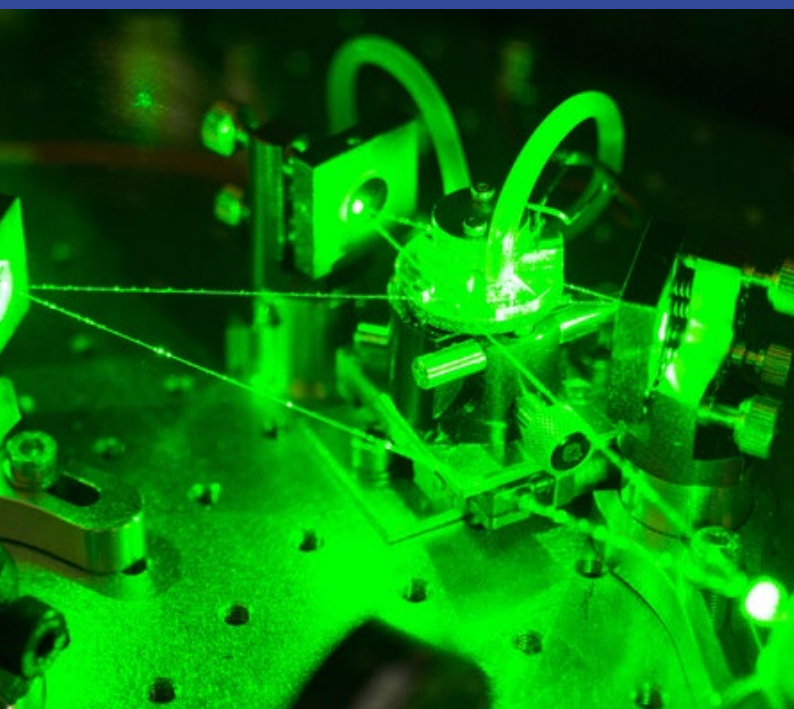


universität freiburg

Handbook of Modules

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

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



Fach / <i>Subject</i>	Angewandte Physik / <i>Applied Physics</i>
Abschluss / <i>Degree</i>	Master of Science (M.Sc.)
Prüfungsordnung / <i>Examination regulations</i>	PO 2016
Art des Studiengangs / <i>Type of degree</i>	konsekutiv / <i>consecutive</i>
Studienform / <i>Study form</i>	Vollzeitstudium / <i>full time study</i>
Studiendauer / <i>Duration of study</i>	4 Semester (Regelstudienzeit) / <i>4 semester (regular duration of study)</i>
Unterrichtssprache / <i>Language of instruction</i>	englisch / <i>English</i>
Studienbeginn / <i>Start of studies</i>	Winter- oder Sommersemester / <i>winter or summer semester</i>
Hochschule / <i>University</i>	Albert-Ludwigs-Universität Freiburg
Fakultät / <i>Faculty</i>	Fakultät für Mathematik und Physik / <i>Faculty for Mathematics and Physics</i>
Institut / <i>Institute</i>	Physikalisches Institut / <i>Institute of Physics</i>
Internetseite / <i>Website</i>	www.physik.uni-freiburg.de
Profil des Studiengangs / <i>Profile of the study program</i>	<p><i>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.</i></p> <p><i>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.</i></p> <p><i>The Master's program offers the possibility for an optional specialization in Quantum Science and Technology, if the students choose their courses accordingly.</i></p>
Ausbildungsziele / Qualifikationsziele des Studiengangs <i>Qualification goals of the study program</i>	<p>Fachliche Qualifikationsziele / <i>Professional qualification goals:</i></p> <ul style="list-style-type: none"> ■ <i>Consolidation of advanced knowledge in physics and its applications in physical sciences and related areas</i> ■ <i>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</i> ■ <i>Ability to apply modern methods, techniques and concepts in physical sciences and related areas as well as to implement them efficiently</i> ■ <i>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</i> ■ <i>Experience with working processes in joint research projects at research institutions and large-scale research facilities</i>

	<ul style="list-style-type: none"> ■ <i>Capability to communicate scientific results in written reports and in presentations to an academic audience</i> <p>Überfachliche Qualifikationsziele / <i>General qualification goals:</i></p> <ul style="list-style-type: none"> ■ <i>Ability to pursue independent, responsible and creative scientific work</i> ■ <i>Ability to organize, carry out and manage complex projects</i> ■ <i>Preparation to take on management responsibility and to supervise, lead and guide others</i> ■ <i>Ability to operate in a professional environment</i> ■ <i>Acquisition of abstraction skills, system-analytical thinking, teamwork and communication skills</i> ■ <i>International and intercultural experience</i> ■ <i>Social responsibility</i>
<p>Zulassungsvoraussetzungen</p> <p><i>Admission requirements</i></p>	<p>Qualifizierter Bachelor-Abschluss in Physik oder einem gleichwertigen Studiengang. Außerdem / <i>Qualifying bachelor's degree in physics or an equivalent degree course. In addition</i></p> <ul style="list-style-type: none"> ■ 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)

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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	Compulsory/ Elective	Recommended 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.

FS	Module					total ECTS
1	Advanced Experimental Physics 9 ECTS	Applied Physics 18 ECTS		Term Paper 6 ECTS	Master Laboratory Applied Physics 8 ECTS	28
2	Advanced Theoretical Physics 9 ECTS		Elective Subjects 10 ECTS			32
3	Research Traineeship 30 ECTS					30
4	Master Thesis (Thesis and Presentation) 30 ECTS					30

2.2. Optional Specialization

2.2.1. Specialization in “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:

FS	Module				
1	Advanced Atomic and Molecular Physics (Exp WiSe) or Advanced Condensed Matter I (Exp WiSe) or Advanced Optics and Lasers (Exp SoSe) 9 ECTS	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		Term Paper 6 ECTS	Master Laboratory Applied Physics 8 ECTS
2	Quantum Information Theory* (Theo SoSe) 9 ECTS		Elective Subjects 10 ECTS		
3	Research Traineeship in Quantum Science and Technology* 30 ECTS				
4	Master Thesis in Quantum Science and Technology* (Thesis and Presentation) 30 ECTS				

* 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

2.2.2. Specialization in “Applied Condensed Matter Physics”

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:

FS	Module					total ECTS
1	Advanced Experimental Physics 9 ECTS	Applied Physics 18 ECTS		Term Paper 6 ECTS	Master Laboratory Applied Physics 8 ECTS	28
2	Advanced Theoretical Physics 9 ECTS		Elective Subjects 10 ECTS			32
3	Research Traineeship in Applied Condensed Matter Physics*					30
4	Master Thesis in Applied Condensed Matter Physics* (Thesis and Presentation)					30

* These components are mandatory

The following courses can be selected in the modules Advanced Experimental and Theoretical Physics:

Advanced Experimental Physics

- Condensed Matter Physics I: Solid State Physics (Exp, WiSe)
- Condensed Matter Physics II: Interfaces and Nanostructures (Exp, SoSe)

Advanced Theoretical Physics

- Theoretical Condensed Matter Physics (Theo, SoSe)
- Classical Complex Systems (Theo, WiSe)
- Computational Physics: Materials Science (Theo, SoSe)
- Advanced Quantum Mechanics (Theo, WiSe)

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 and 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	<ul style="list-style-type: none"> • 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	irregular
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)

Module no. 07LE33M-ADV_EXP_AMO	Advanced Atomic and Molecular Physics			
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 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.			
Course content	<ul style="list-style-type: none"> • 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 			
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			

3.1.2. 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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)

Module no. 07LE33M-ADV_EXP_CM1	Condensed Matter I: Solid State Physics			
Lecturer/s	Lecturers from Experimental Condensed Matter and Applied 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	<ul style="list-style-type: none"> • 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 			
Course content	<ul style="list-style-type: none"> • Atomic structure of matter • lattice dynamics, phonons • electronic structure of materials • optical properties • magnetism/superconductivity 			
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			

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

Module no. 07LE33M-ADV_EXP_CM2	Condensed Matter II: Interfaces and Nanostructures			
Lecturer/s	Lecturers from Experimental Condensed Matter and Applied 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	<ul style="list-style-type: none"> • 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 reconstruction, 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. 			
Course content	<ul style="list-style-type: none"> • Surfaces and interface • structure formation on surfaces • self-assembly, morphology and transitions • optical and electronic properties 			
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			

3.1.5. Particle Detectors (9 ECTS)

Module no. 07LE33M- ADV_EXP_PDET	Particle Detectors			
Lecturer/s	Lecturers from Experimental Particle 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	<ul style="list-style-type: none"> • 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 			
Course content	<ul style="list-style-type: none"> • 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 			
Previous knowledge	Experimental Physics V (Nuclear and Particle physics) (B.Sc. Physics) Experimental Physics IV (Atoms, Molecules, Solid State Physics) (BSc. Physics)			
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			

3.1.6. 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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)

Module 07LE33K-ADV_THEO	Advanced Theoretical Physics						9 ECTS
Responsibility	Dean of Studies, Lecturers for Theoretical Physics						
Courses		Type	Credit hrs	ECTS	Assessment	Semester	
	Advanced Theoretical Physics	L	4	9	PL: written or oral exam	WiSe + SoSe	
	Advanced Theoretical Physics	E	2	9	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	<ul style="list-style-type: none"> • 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. 						
Course content	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.						
Workload (hours)	Course	Type	Contact hrs	Self-studies	Total		
	Advanced Theoretical Physics	L	60 h	180 h	270 h		
	Advanced Theoretical 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 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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)

Module no. 07LE33M-ADV_THEO_CS	Classical Complex Systems			
Lecturer/s	Lecturers from Theoretical Atomic, Molecular and Optical Sciences or 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 winter term.			
Qualification objectives	<ul style="list-style-type: none"> • 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. 			
Course content	<p>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.</p> <p>Stochastic Processes:</p> <ul style="list-style-type: none"> • Random walks, Markov model • Stochastic differential equations and master equations (Langevin- and Fokker-Planck Equation) • Numerical treatment and Monte Carlo techniques <p>Non-Linear Dynamics / Chaos Theory:</p> <ul style="list-style-type: none"> • Dynamical systems (discrete, differential equations, Hamiltonian) • Lyapunov exponents • Attractors and bifurcations <p>Applications:</p> <p>Molecular dynamics simulations</p> <ul style="list-style-type: none"> • Molecular driving forces and force field models • Simulation techniques and sampling • Energy landscapes and analysis of dynamics <p>Time series analysis and inverse problems</p> <ul style="list-style-type: none"> • Estimation and test theory • Spectral analysis • State space model 			

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)

Module no.	Complex Quantum Systems			
07LE33M- ADV_THEO_CQS				
Lecturer/s	Lecturers from Theoretical Atomic, Molecular and Optical Sciences or 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	Lecture is offered on an irregular basis.			
Qualification objectives	<ul style="list-style-type: none"> • 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. 			
Course content	<ul style="list-style-type: none"> • 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 <p>Applied Track:</p> <ul style="list-style-type: none"> • 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 <p>Structural Track:</p> <ul style="list-style-type: none"> • Uncertainty relations: Joint measurability, uncertainty relations for continuous and discrete observables, information-disturbance trade-off • Contextuality: Non-Locality, Bell's Theorem, Marginals 			
Previous knowledge	Theoretical Physics IV (Quantum Mechanics, B.Sc. Physik) and Advanced Quantum Mechanics (M.Sc. Physics)			

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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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)

Module no. 07LE33M- ADV_THEO_QIT	Quantum Information Theory			
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 summer term.			
Qualification objectives	<ul style="list-style-type: none"> • Students are familiar with the main concepts of quantum information theory. • Students are familiar with the main differences between classical and quantum computing. 			
Course content	<p>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.</p> <ol style="list-style-type: none"> 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) 			
Previous knowledge	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

3.2.7. Computational Physics: Materials Science (9 ECTS)

Module no. 07LE33M- ADV_THEO_COMPPHYS	Computational Physics: Materials Science			
Lecturer/s	Lecturers from Computational Physics			
Course details	Type	Credit hrs	ECTS	Assessment
	Lecture and exercises (L+E)	4+2	9	PL: written or oral exam
Term	The lecture is offered regularly in the summer term.			
Qualification objectives	<ul style="list-style-type: none"> • 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. 			
Course content	<p>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.</p> <p>The lecture is accompanied by a hands-on programming course. Classical molecular dynamics simulations will be used to study metallic and covalently bonded materials.</p>			
Previous knowledge	Basic knowledge in classical and 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 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

3.3. Applied Physics (18 ECTS)

Module 07LE33K-APHYS	Applied Physics						18 ECTS
Responsibility	Dean of Studies, Lecturers of the Institute of Physics and associated Institutes						
Courses		Type	Credit hrs	ECTS	Assessment	Semester	
	Applied Physics lectures by own choice	L+E	According to selected courses	18	SL: written or oral exam (9 ECTS) PL: written or oral exam (9 ECTS)	WiSe + SoSe	
	Total:			18			
Organization	Students select different lectures in order collect at least 18 ECTS credits in total from the list of Applied Physics lectures given below.						
Required academic assessment	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.						
Grading	The final grade of the module is the ECTS-weighted mean of the grades of the graded exams (PL).						
Qualification objectives	The qualification objects are subject to the selected course and are listed in the individual course descriptions.						
Course content	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.						
Workload (hours)	Course		Contact hrs	Self-studies		Total	
	Applied Physics lectures		subject to selected lectures		540 h		
	Total:				540 h		
Usability	M.Sc. Applied Physics						
Previous knowledge	Specific prerequisites are given in the individual course descriptions.						
Language	English						

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 photovoltaic	3		X	
Physics in Life Science & Medical Physics:					
07LE33M-BIOPHYS	Biophysik – Grundlagen und Konzepte	7	X		
07LE33M-DYNBIO	Dynamic Systems in Biology	7			X
07LE33M-MOLDYN	Molecular Dynamics & Spectroscopy	7			X
07LE33M-SELFORG	Cellular Self-Organization and Molecular Machines	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: Biological Learning, Control and Decision Making	9		X	
07LE33M-Neuro	Computational Neuroscience: Neural Computation	3		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-SQD	Semiconductor and Quantum 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)

Module no. 07LE33M-MOIF	Physics of microscopy and image formation			
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 winter term			
Qualification objectives	<p>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 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, fluorescence depletion through stimulated emission (STED) or multi-wave mixing by coherent anti-Stokes Raman scattering (CPLS).</p> <p>The tutorials help the student to get a more in-depth and thorough understanding of the lecture. Here, a special focus is put on the transfer of knowledge obtained in the lecture. To achieve this, the students should prepare weekly exercises and present them during the tutorial. Only difficult exercises are presented by the tutors.</p>			
Course content	<p>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.</p> <p>Topics:</p> <ol style="list-style-type: none"> 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 <p>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.</p>			

Literature	<p>Optical Microscopy:</p> <ul style="list-style-type: none"> • 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 <p>General Optics:</p> <ul style="list-style-type: none"> • 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)

Module no. 07LE33M-BIOPHYS	Biophysik - Grundlagen und Konzepte			
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 winter term			
Qualification objectives	<p>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.</p> <p>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.</p> <p>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.</p>			
Course content	<p>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.</p> <p>Inhalte:</p> <ol style="list-style-type: none"> 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 			
Literature	<ul style="list-style-type: none"> • 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 			
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	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	<p>In this lecture students will learn</p> <ul style="list-style-type: none"> the transfer from the Maxwell equations and the electromagnetic force density to optical forces and optical tweezers, which allow to control molecular processes relevant to cellular biology and medicine. the basics of light scattering, how photons transfer momentum to microscopic objects and how scattered photons transfer information about the state of the objects. In contrast to incoherent photons, coherent light encodes significantly more information about small objects, which, driven by thermal forces, continuously change their position and orientation relative to their environment. All this can be directly measured through μs-nm particle tracking. how smallest probes can interact on a molecular scale with their environment, which can be analyzed by correlations of changes in the probe's states. In this way, the interactions of probes with living cells give new insights into cellular diseases, such as bacterial and viral infections, but also exposure of particulate matter to lung cells. 			
Course content	<ul style="list-style-type: none"> Introduction Light – Carrier of Information and Actor Microscopy und Light Focussing Light Scattering Manipulation by Optical Forces Particle Tracking beyond the Uncertainty Regime Thermal Motion and Calibration Photonic Force Microscopy Applications in Biophysics and Medicine Time-Multiplexing and holographic optical traps Applications in Micro- and Nano-Technology Appendix 			
Literature	<p>General optics:</p> <ul style="list-style-type: none"> Hecht, E. (2002). Optics, Addison Wesley. Saleh, B. E. A. and M. C. Teich (1991). Fundamentals of Photonics, Wiley & Sons <p>Nano optics</p> <ul style="list-style-type: none"> L. Novotny & B. Hecht, E. (2002). Principles of Optics, Cambridge. <p>Statistical physics and thermodynamics</p> <ul style="list-style-type: none"> Standard text books 			

	Chemical and biological forces and interactions <ul style="list-style-type: none"> 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	<p>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.</p>			
Course content	<p>1. Introduction Some motivation, literature and a bit of history</p> <p>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.</p> <p>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?</p> <p>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.</p> <p>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.</p>			

	<p>6. Light Scattering and Plasmonics</p> <p>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 extend 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.</p>			
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)

Module no. 07LE33M-LSPEC	Laser-based Spectroscopy and Analytical Methods			
Lecturer/s	PD Dr. Frank Kühnemann (Fraunhofer IPM)			
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 term			
Qualification objectives	<p>At the end of the course, the students</p> <ul style="list-style-type: none"> • 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. 			
Course content	<p>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.</p> <p>The lecture block in the first half of the course will give a comprehensive introduction into the following topics</p> <ul style="list-style-type: none"> • Infrared molecular spectra • Tuneable lasers • Spectroscopic techniques (absorption, photoacoustic spectroscopy, cavity-based methods) • Background signals, noise and detection limits <p>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.</p>			
Literature	<ul style="list-style-type: none"> • lecture script • recommended literature will be announced in the lecture 			
Preliminaries / Previous knowledge	Advanced Optics and Lasers (recommended)			

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)

Module no. 07LE33M-PHOTOVOLT	Photovoltaic Energy Conversion			
Lecturer/s	Dr. Uli Würfel (Fraunhofer ISE), Prof. Dr. Andreas Bett (Fraunhofer ISE)			
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 winter term			
Qualification objectives	<ul style="list-style-type: none"> • 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 			
Course content	<ul style="list-style-type: none"> • 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 			
Literature	<ul style="list-style-type: none"> • lecture script • P. Würfel, Physics of Solar Cells, 2nd edition 2009, Wiley VCH 			
Preliminaries / Previous knowledge	Basic knowledge of semiconductor physics is helpful but not mandatory			
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			

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

Module no. 11LE68MO-4103	Multi-junction solar cell technology and concentrator photovoltaic			
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 summer term			
Qualification objectives	<ul style="list-style-type: none"> • Students have a profound understanding of the concept of multi-junction solar cells and the underlying physical principles. • Students are familiar with concentrator photovoltaics and characterization & manufacturing of CPV systems 			
Course content	<ul style="list-style-type: none"> • 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 characterisation of III-V materials and multi-junction solar cells • PV concentrator technology: low and high concentration • components of CPV systems: optics, cells, manufacturing • CPV system analysis including an economical evolution 			
Literature	<ul style="list-style-type: none"> • "Solar Cells and Their Applications", L. Fraas, L. Partain, Wiley, 2010; • "Advanced Concepts 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 Photovoltaics", 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)

Module no. 07LE33M-DYNBIO	Dynamic Systems in Biology			
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	<ul style="list-style-type: none"> • 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. 			
Course content	<ul style="list-style-type: none"> • Numerical integration of differential equations • Mathematical biology • Population models • Hodgkin-Huxley model • Turing model • Enzyme kinetics • Systems biology • Metabolism • Signal transduction • Gene regulation 			
Literature	<ul style="list-style-type: none"> • J.D. Murray. Mathematical Biology, Springer 			
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			

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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Time-Dependent Quantum Dynamics • Density Matrix Theory • Quantum-Classical Formulation • Linear Spectroscopy • Nonlinear Techniques • Multidimensional Spectroscopy 			
Literature	<ul style="list-style-type: none"> • 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. Cellular Self-Organization and Molecular Machines (5 ECTS)

Module no. 07LE33M- SELFORG	Cellular Self-Organization and Molecular Machines			
Lecturer/s	Prof. Dr. Thorsten Hugel, 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 • Self-organization and phase separation • Methods to measure cellular self-organization and molecular machines 			
Literature	<ul style="list-style-type: none"> • 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.			
Final Exam	Written (120 min) or oral exam (30 min)			
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	<ul style="list-style-type: none"> • 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	<p>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:</p> <ul style="list-style-type: none"> • overview over the physics of medical imaging • Magnetic Resonance Imaging (MRI) <ul style="list-style-type: none"> ○ 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 <ul style="list-style-type: none"> ○ principles of radio-tracer detection ○ scintigraphy ○ single photon emission computed tomography (SPECT) ○ positron emission tomography (PET) • ultrasound (US) <ul style="list-style-type: none"> ○ sound generation and propagation in tissue ○ US imaging ○ Doppler US ○ therapeutic applications of US (Lithotripsy) • X-ray Imaging <ul style="list-style-type: none"> ○ properties and generation of X-rays ○ fluoroscopy ○ computed tomography ○ image reconstruction from projections • role of medical imaging in <ul style="list-style-type: none"> ○ the detection of disease ○ in patient management • therapy monitoring 			

Literature	<ul style="list-style-type: none"> • 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)

Module no. 07LE33M-CARDI	Biophysics of cardiac function and signals			
Lecturer/s	Dr. Viviane Timmermann, Prof. Dr. Jens Timmer			
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	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.			
Course content	<ul style="list-style-type: none"> • 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 			
Literature	<ul style="list-style-type: none"> • lecture slides 			
Preliminaries / Previous knowledge	Basic interest in biology and computational modelling. Knowledge in Matlab or Python are beneficial			
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			

3.3.13. Computational Neuroscience: Biological Learning, Control and Decision Making (9 ECTS)

Module no. 07LE33M-Neuro 09LE03Ü-NE-2-T1.2_b	Computational Neuroscience: Biological Learning, Control and Decision Making			
Lecturer/s	Prof. Dr. Stefan Rotter (Faculty of Biology, Bernstein Center Freiburg)			
Course details	Type	Credit hrs	ECTS	Assessment
	Lecture and exercises (L+E)	6	9	SL or PL
Term	The lecture is offered in the summer term.			
Qualification objectives	<p>The students acquire the competence to</p> <ul style="list-style-type: none"> • summarize models of biological learning, control and decision making • link mathematical models with biological phenomena arising in systems neuroscience, using theory and computer simulations • explain the fundamental trade-off between biological detail and mathematical abstraction and evaluate its consequences • explain the steps necessary to develop and validate models of behaviour their underlying neural mechanisms • explain the gain in understanding biological mechanisms arising from the study of mathematical models and critically discuss the limits of mathematical modelling • implement, simulate and analyse models and methods of biological learning, control and decision making • compare models of different levels of abstraction 			
Course content	<p>Building on prior knowledge in neuroscience and mathematical methods, this course covers the computational neuroscience and modelling of biological learning, control and decision-making. Topics include:</p> <ul style="list-style-type: none"> • Biological movement control • Sensorimotor learning and motor adaptation • Reinforcement learning in neuroscience • Bayesian models in action and perception • Neural networks of learning and control • Brain-machine interfaces to study learning and control <p>Several of the methods and models covered in this course are related to developments in artificial intelligence and machine learning and thus, connections between models of brain function and AI will be a topic of discussion in this course.</p> <p>The course consists of interactive lectures and accompanying exercises.</p>			
Literature				
Preliminaries / Previous knowledge (recommended)	<ul style="list-style-type: none"> • Basic knowledge in the biological foundations of neuroscience • Basic knowledge of quantitative methods • Enjoying mathematical modelling 			

	<ul style="list-style-type: none"> • Quantitative Methods and Statistics course • Python programming • Scientific Programming in Python course 			
Final Exam	PL: Written exam (70 minutes duration), SL: Presentation of selected exercise solutions (approx. 15 min.)			
Workload (hours)	Course	Contact hrs	Self-studies	Total
	Lecture and exercises (L)	78 h	192 h	270 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: Neural Computation (3 ECTS)

Module no. 07LE33M-Neuro 09LE03Ü-NE-2-T1.4	Computational Neuroscience: Neural Computation			
Lecturer/s	Prof. Dr. Stefan Rotter (Faculty of Biology, Bernstein Center Freiburg)			
Course details	Type	Credit hrs	ECTS	Assessment
	Simulation exercises (E)	3	3	SL or PL
Term	The lecture is offered regularly in the summer term. (will not be offered in SoSe 25 and SoSe 26, next availability in SoSe 27)			
Qualification objectives	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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/).			
Final Exam	Written exam (120 min), oral exam (60 min) or term paper (10 pages), in combination with course above.			
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 on an irregular basis			
Qualification objectives	<ul style="list-style-type: none"> • Students get to know fundamental concepts in polymer physics. • They are familiar with experimental techniques for the characterization of polymers. 			
Course content	<p>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.</p>			
Literature	<ul style="list-style-type: none"> • 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	<p>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)</p>			
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 macroscopic sizes. They will understand the physics of how molecules or objects put themselves together without guidance or management from an outside source.			
Course content	<p>Goal:</p> <p>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-molecular 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.</p> <p>Preliminary program:</p> <p>"Physical laws for making compromises"</p> <p>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.</p> <p>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.</p>			
Literature	<ul style="list-style-type: none"> • 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)

Module no. 07LE33M- HL	Fundamentals of Semiconductors & Optoelectronics			
Lecturer/s	Dr. Stefan Janz, Prof. Andreas Bett (Fraunhofer ISE)			
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 winter term			
Qualification objectives	<ul style="list-style-type: none"> • 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. 			
Course content	<ul style="list-style-type: none"> • 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 			
Literature	<ul style="list-style-type: none"> • H. Ibach, H. Lüth, „Festkörperphysik" (Springer, 2009) • K. Seeger, „Semiconductor Physics" (Springer, 2004) • P. Yu, M. Cardona, „Fundamentals of Semiconductors" (Springer, 2010) 			
Preliminaries / Previous knowledge	Solid-state physics and theoretical physics at 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 or German			

3.3.18. Semiconductor and Quantum Devices (5 ECTS)

Module no. 07LE33M-SQD	Semiconductor and Quantum Devices			
Lecturer/s	Dr. Florentin Reiter (Fraunhofer IAF), Prof. Andreas Bett (Fraunhofer ISE)			
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 term			
Qualification objectives	<ul style="list-style-type: none"> • Students are familiar with fundamental concepts of semiconductor physics • They understand the principles of basic and advanced semiconductor devices • They can describe the basics of semiconductor quantum devices and qubits 			
Course content	<ul style="list-style-type: none"> • Transport phenomena • Metal-semiconductor-contact, Schottky diode • p-n junction: diode rectifier, photodiode, LED, laser diode, solar cell • Bipolar transistors, HBT • Field effect-transistors (JFET, MOSFET, HEMT) • Quantum structure-elements (RTD, QWIP, QCL) • Qubits and quantum devices based on semiconductors: quantum dots and color centers in diamond 			
Literature	S.M. Sze and K. K. Ng, Physics of Semiconductor Devices, Wiley, 2006			
Preliminaries / Previous knowledge	Experimental physics IV (solid-state physics), lecture "Fundamentals of Semiconductors and Optoelectronics" (Dr. Stefan Janz)			
Final Exam	Oral exam (30 min)			
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 or German			

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	<ul style="list-style-type: none"> • 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 <ul style="list-style-type: none"> ○ Intrinsic stresses ○ Elastic and plastic behavior ○ Adhesion properties • Principles and loading conditions in functional materials for actors & sensors. 			
Literature	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<p>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.</p> <p>The lecture series comprises courses on, e.g., these topics:</p> <ul style="list-style-type: none"> • 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. <p>The content of each course will be announced for each semester.</p>			
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)

Module no. 07LE33M- QTRANS	Quantum Transport			
Lecturer/s	PD Dr. Michael Walter			
Course details	Type	Credit hrs	ECTS	Assessment
	Lecture and exercises (L+E)	3+2	7	SL or PL
Term	The lecture is offered irregularly in the summer term.			
Qualification objectives	<ul style="list-style-type: none"> • 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 			
Course content	<p>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.</p>			
Literature	<ul style="list-style-type: none"> • 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). 			
Previous knowledge	Basic quantum mechanics			
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			

3.3.22. 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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. Modelling and System Identification (6 ECTS)

Module no. 11LE50MO-2080	Modelling and System Identification			
Lecturer/s	Prof. Dr. Moritz Diehl (IMTEK)			
Course details	Type	Credit hrs	ECTS	Assessment
	Lecture and exercises (L+E)	2+2	6	SL or PL
Term	The lecture is offered regularly in the winter semester.			
Qualification objectives	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.			
Course content	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.			
Literature	<ul style="list-style-type: none"> • Lecture manuscript • Ljung, L. (1999). System Identification: Theory for the User. Prentice Hall • Lecture manuscript "System Identification" 			
Preliminaries / Previous knowledge	Differential Equations, Systems Theory and Feedback Control			
Workload (hours)	Course	Contact hrs	Self-studies	Total
	Lecture and exercises (L+E)	60 h	120 h	180 h
Usability	M.Sc. Physics: Elective Subjects (SL), M.Sc. Applied Physics: Applied Physics (PL or SL) or Elective Subjects (SL)			
Language	English			

3.4. Elective Subjects (10 ECTS)

Module 07LE33K-ELSUB_APHYS	Elective Subjects						10 ECTS
Responsibility	Dean of Studies, or Faculty/Institute responsible for selected course						
Courses		Type	Credit hrs	ECTS	Assess- ment	Semester	
	Advanced Physics or Applied Physics or Mathematics lectures or courses from other M.Sc./M.A. programs by own choice	L+E	According to selected courses	10	SL: written or oral exam	WiSe + SoSe	
	Total:			10			
Required academic assessment	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.						
Grading	unmarked						
Qualification objectives	The qualification objects are subject to the selected course.						
Course content	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.						
Workload (hours)	Course		Contact hrs	Self-studies		Total	
	Elective courses		subject to selected courses		300 h		
	Total:				300 h		
Usability	M.Sc. Applied Physics						
Previous knowledge	Subject to selected courses						
Language	Subject to selected courses						

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	<ul style="list-style-type: none"> • 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	<p>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.</p> <p>The <i>Term Paper</i> seminar comprises approximately 10 presentations from a coherent field of physics or a neighbouring scientific area.</p>						
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: experimental 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	<ul style="list-style-type: none"> • 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	<p>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.</p> <p>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.</p>				
Grading	ungraded				
Qualification objectives	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 <i>Master Laboratory</i> and of three of the four marked courses (AR) of the modules <i>Advanced Quantum Mechanics</i> , <i>Advanced Physics 1</i> , <i>Advanced Physics 2</i> , and <i>Term Paper</i> .				
Language	English				

3.8. Master Thesis (30 ECTS)

Module 07LE33M-MSC	Master Thesis				30 ECTS
Responsibility / Supervision	Group leaders at the Institute of Physics and associated Institutes				
Module details	Type		ECTS	Assessment	
	Master Thesis	6 months	28	PL: final thesis	
	Master Colloquium	45 min	2	SL: oral presentation	
	Total:		30		
Organisation	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.				
Grading	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).				
Qualification objectives	<ul style="list-style-type: none"> • 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. 				
Module content	<ul style="list-style-type: none"> • 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. 				
Workload (hours)	900 h distributed over a six-month period. This workload includes research, preparation of the written thesis and preparation of the final presentation.				
Usability	M.Sc. Physics, M.Sc Applied Physics				
Precondition	Admission to the Master Thesis requires successful accomplishment of the module <i>Research Traineeship</i> .				
Language	English or German				

