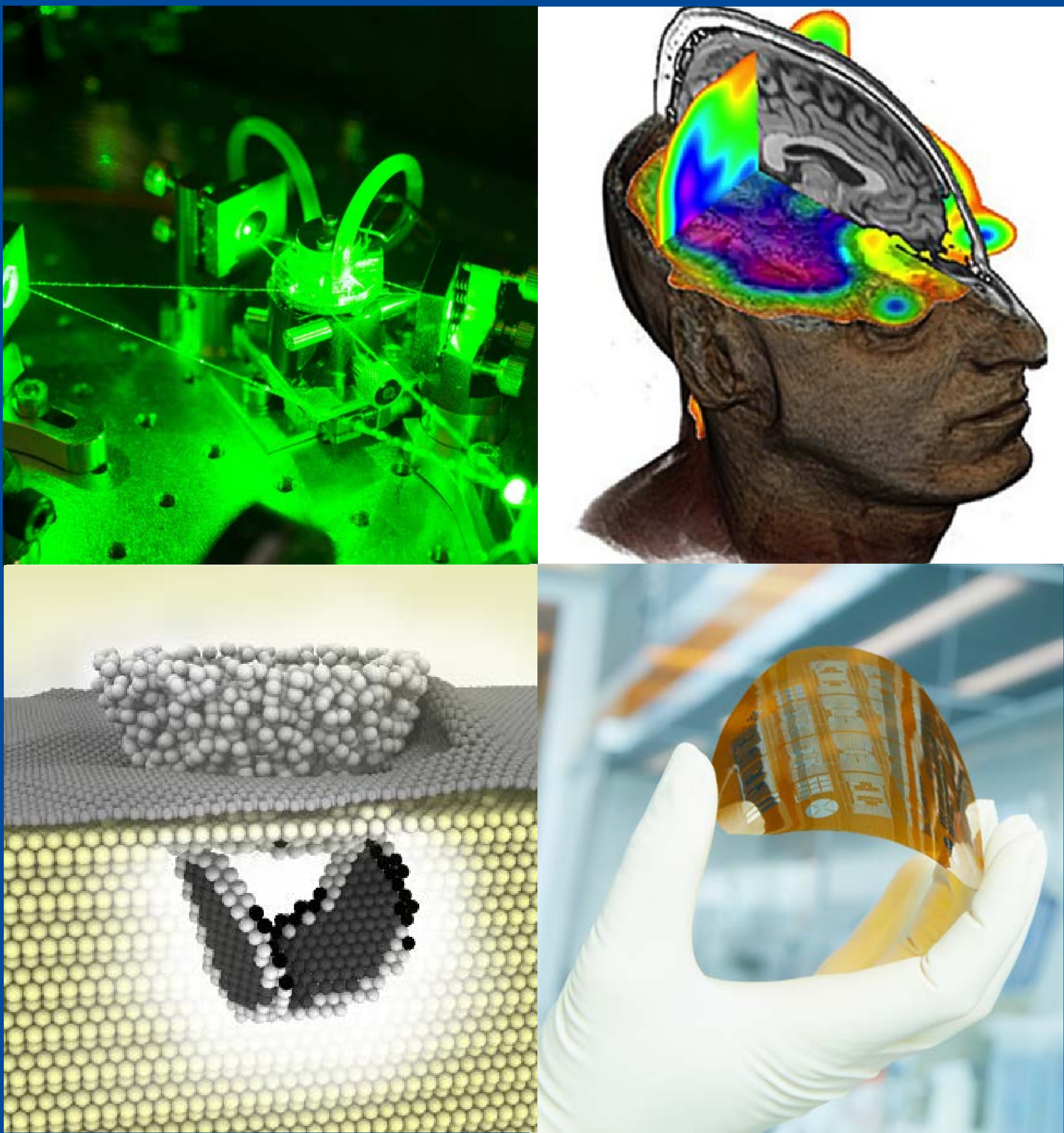
Albert-Ludwigs Universität Freiburg
Physikalisches Institut

Handbook of Modules



Master of Science (M.Sc.)
Applied Physics

Front cover

top left: *Laser system – Group Prof. Schätz, Physics Institute*
top right: *Surface rendering of a conventional clinical proton MRI data set (in greyscale) in combination with a 17O-MRI (in color) – Group Prof. Hennig/Prof. Bock, Uniklinikum Freiburg (© M. Bock / Uniklinik FR)*
bottom left: *Atomistic simulation of mechanical wear of a graphene covered surface – Group Prof. Moseler, Physics Institute & Fraunhofer IWM*
bottom right: *Micro-structuring – © Fraunhofer IPM*

Preliminary notes:

The module handbook does not substitute the course catalogue (Vorlesungsverzeichnis), which is updated every semester to provide variable information about the courses (e.g. time and location).

Note that only the Examination Regulations (Prüfungsordnung) are legally binding.

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“)
PL	Exam („Prüfungsleistung“)
L	Lecture
E	Exercise/Tutorials
S	Seminar
Lab	Laboratory
SoSe	Summer semester (summer term)
WiSe	Winter semester (winter term)
ECTS	Credit Points based on the European Credit Transfer System (ECTS-Points)

Table of Contents

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

1.1. The Master Program

The Institute of Physics is actively involved in a wide range of research areas with students enjoying a broad diversity of topics covered by lecture courses and seminars. The diversity and quality of the research and teaching program of the institute, embedded in the rich and interdisciplinary research landscape defined through the University of Freiburg, the local Fraunhofer institutes and other institutions committed to research and development in the larger Freiburg area are key ingredients for the attractiveness of the institute nation-wide, but also at the international level.

The English-taught M.Sc. Applied Physics aims to continue and broaden studies begun at bachelor level. It provides an interdisciplinary study program at the interface between fundamental physical concepts and resulting modern technologies. Participants will deepen their knowledge in modern physics and are introduced to central methods of physical research, like measuring techniques, methods for data analysis or numerical simulation. In cooperation with associated institutes of the university, the university medical center and with the Fraunhofer institutes in Freiburg, the Master's program offers the possibility for specialization in a particular area of applied physics, such optical technologies, physics in life and medical sciences, or interactive and adaptive materials.

In the first year of their studies, participants consolidate their knowledge by attending lectures on advanced theoretical and experimental physics, as well as applied physics courses, which can be selected from a wide range of topics. Each semester students may choose among various term papers, where they improve their oral presentation skills and prepare written handouts in English on a specific topic of modern research. In addition, students may widen their view by selecting from a variety of elective courses in physics, or from course offered by other faculties.

During their final one-year Master thesis, students specialize in a particular field by participating in a cutting-edge research project at the Institute of Physics, the Universitätsklinikum (University clinical research center) or one of the associated research institutes and centers. Successful completion of the Master program qualifies for a scientific career at interdisciplinary research institutions, or a profession in industry.

1.2. Admission to the Master Program

Application to the M.Sc. program is possible both, for the winter and summer semester. The application deadline for the summer semester is **January 15** and for the winter semester **July 15** each year.

Applicants must hold a Bachelor’s degree in physics or equivalent with above average academic performance. The admission committee decides on the equivalence of the degree. According to the admission regulations applicants must also have a working knowledge of English and are required to provide appropriate evidence of their language skills. An adequate certification of the English language skills is for example the school-leaving certificate of a German Gymnasium (Abitur). Applicants who do not hold an "Abitur" are required to provide a B 2 (CEFR) certificate or equivalent for the English language (e.g. TOEFL, or EILTS). Native speakers of English are not required to provide proof of language proficiency in their mother tongue.

The application form is available online on the webpage of the Physics Institute at http://www.physik.uni-freiburg.de/studium/MSc_ApplPhysics.

1.3. Program Structure

The Physics Institute 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.

The M.Sc. Applied Physics comprises the following modules:

Module	Type	Lecture hours	ECTS	Compulsory/ Elective	Recommended semester	Assessment
Advanced Experimental Physics	L + E	4 + 2	9	E	1 or 2	PL written or oral
Advanced Theoretical Physics	L + E	4 + 2	9	E	1 or 2	PL written or oral
Applied Physics	L + E	variable	18	E	1 or 2	PL written or oral
Elective Subjects	variable	variable	10	E	1 or 2	SL
Term Paper	S	2	6	E	1 or 2	PL written and oral
Master Laboratory Applied Physics	Lab	10	8	C	1 or 2	PL written and oral
Research Traineeship	-	-	30	C	3	SL
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;
PL = exam (‘Prüfungsleistung’); SL = assessed coursework (‘Studienleistung’)

1.4. 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 programs at different institutions and different countries.

The ECTS credit points of a module determine the time requirements for this module, with one ECTS point 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.

1.5. Contents of Modules

Advanced Experimental Physics (9 ECTS credit points)

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

Advanced Theoretical Physics (9 ECTS credit points)

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

Applied Physics (18 ECTS credit points)

Within this elective module students may select various **Applied Physics** courses by their own choice. Eligible courses are listed in section 3.3 and in the course catalogue for the current semester. The final module exam 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 credit points)

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 proof successful participation, so that the examination office of physics can transfer the credits.

Term Paper (6 ECTS credit points)

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 credit points)

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. Details on the experiments are given in section 3.6. Successful completion of the Master Laboratory Applied Physics is prerequisite for beginning the Research Traineeship.

Research Traineeship (30 ECTS credit points)

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 credit points)

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.

1.6. Determination of final mark

The individual module marks contribute to the final mark 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. Organization of studies

2.1. Study plan

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

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

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

2.2. Specialization

Recommendation: Successfully accomplishing the Research Traineeship and the following Master Thesis often requires an appropriate choice of lectures and courses in the first year. It is therefore recommended to select a particular field of specialization at an early stage and to select the courses accordingly.

2.3. (Online-) Registration

During their studies students have to participate in various courses as well as take part in examinations. Registration to courses and exams is in the student's own responsibility.

Participation in courses

In order to participate in the Master Laboratory Applied Physics students have to register in due time with the examination office. For the participation in lectures or tutorials, usually no separate registration is required.

Registration for exams

For the participation in exams, an early registration is mandatory. The examinations office announces the modalities for registration. Typically students register online via the HISinOne Campus-Management System (https://campus.uni-freiburg.de) or directly at the examination office of the Physics Institute. A registration in due time is in the responsibility of the students. Registration periods (typically beginning of the semester until three weeks before the end of the term) are announced by the examinations office.

2.4. Forms of assessment

There are various forms of assessing a student's performance such as written and oral exams, participation in exercises, or written reports. The credits for a certain course are only awarded if these assessments have been successfully passed. The requirements for passing are typically defined and announced by the lecturer at the beginning of each lecture/course.

Course achievements (SL, "Studienleistung") are unmarked forms of assessment and have to be passed in order to receive credit for the respective course. They typically consist of active participation in the lecture and exercises and might include passing a final exam. Course achievements do not contribute to the final mark of the master degree.

Examinations for academic record **(PL, "Prüfungsleistung")** typically consist of a written or oral exam, marked reports or an oral presentation. The received marks contribute to the final mark of the master degree. For participation in these assessments a registration is mandatory (see 2.3).

Retaking examinations

Failed examinations may be retaken 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 permitted to retake 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**	**CP**	**Examina-tion**	**Term**
	Advanced Experimental Physics	L+E	4+2	9	PL	WiSe + SoSe
	Total:			**9**		
Organization	A suitable lecture has to be selected by own choice from the list of Advanced Experimental Physics lectures given below. Students have to register online for the final exam according to the announcements of the examination office.					
Module mark	The final module mark is the mark of the final exam.					
Qualification objectives	• Students obtain advanced knowledge in a particular field of modern 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 for each lecture 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.					
Work load (hours)	**Course**	**Contact time**	**Self-studies**	**Total**		
	Advanced Experimental Physics	90 h	180 h	270 h		

	Total:	90 h	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):

Course No.	Lecture	ECTS	Term		
			WiSe	SoSe	irregu-lar
07LE33V-ADV_EXP_AMO	Advanced Atomic and Molecular Physics	9	X		
07LE33V-ADV_EXP_OL	Advanced Optics and Lasers	9		X	
07LE33V-ADV_EXP_CM1	Condensed Matter I: Solid State Physics	9	X		
07LE33V-ADV_EXP_CM2	Condensed Matter II: Interfaces and Nanostruc-tures	9		X	
07LE33V-ADV_EXP_PDET	Particle Detectors	9	X		

3.1.1. Advanced Atomic and Molecular Physics (9 ECTS)

Lecture 07LE33V-ADV_EXP_AMO	**Advanced Atomic and Molecular Physics**			**9 ECTS**
Lecturer/s	Lecturers from Experimental Atomic, Molecular and Optical Physics			
Course details	**Type**	**Credit hrs**	**CP**	**Examination**
	Lecture and exercises (L+E)	4+2	9	PL
Frequency	In general the course will be offered each WiSe.			
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 employed in atomic clocks, atom interferometers, quantum optics and quantum computing, nanoscale engineering, photochemistry and energy conversion.			
Course content	• 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			
Work load (hours)	**Course**	**Contact time**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Appl. Physics modules: Advanced Experimental Physics (PL), Elective Subjects (SL)			
Language	English			

3.1.2. Advanced Optics and Lasers (9 ECTS)

Lecture 07LE33V-ADV_EXP_OL	**Advanced Optics and Lasers**			**9 ECTS**
Lecturer/s	Lecturers from Experimental Atomic, Molecular and Optical Physics			
Course details	**Type**	**Credit hrs**	**CP**	**Examination**
	Lecture and exercises (L+E)	4+2	9	PL
Frequency	In general the course will be offered each WiSe.			
Qualification objectives	• Students are familiar with the physical concepts of lasers and know the fundamentals of the interaction between laser light and matter. • Students are able to describe in detail the inherent behavior 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 analyze nonlinear optical effects, as e.g. induced by lasers in transparent materials. • Students are familiar with types of lasers, and the applications of lasers			
Course content	• Light-matter interaction: Absorption/emission, line broadening • Coherence & interference: temporal, spatial coherence, interferometers • The laser principle: 2, 3, 4-level lasers, rate equation models, output power of a laser; • Optical resonators: transmission spectra, stability • Laser modes: Paraxial approximation, Gaussian beams, longitudinal and transverse modes, mode selection • Short laser pulses: Dynamic solutions of rate equation, Q-switching, mode locking, intense short pulses, generation of ultra-short laser pulses • Types of lasers and laser applications • Nonlinear optics: Second, third order polarizability, frequency conversion, optical parametric amplification, high-harmonics generation			
Previous knowledge	Experimental Physics I-IV			
Work load (hours)	**Course**	**Contact time**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Appl. Physics modules: Advanced Experimental Physics (PL), Elective Subjects (SL)			
Language	English			

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

Lecture 07LE33V- ADV_EXP_CM1	**Condensed Matter I:** **Solid State Physics**			**9 ECTS**
Lecturer/s	Lecturers from Experimental Condensed Matter and Applied Physics			
Course details	**Form**	**Credit hrs**	**CP**	**Examination**
	Lecture and exercises (L+E)	4+2	9	PL
Frequency	In general the course will be offered each WiSe.			
Qualification objectives	• 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	• Atomic structure of matter • lattice dynamics, phonons • electronic structure of materials • optical properties • magnetism/superconductivity			
Previous knowledge	Experimental Physics I-IV			
Work load (hours)	**Course**	**Contact time**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Appl. Physics modules: Advanced Experimental Physics (PL), Elective Subjects (SL)			
Language	English			

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

<table>
<tr><th>Lecture
07LE33V-
ADV_EXP_CM2</th><th colspan="4">Condensed Matter II:
Interfaces and Nanostructures — 9 ECTS</th></tr>
<tr><td>Lecturer/s</td><td colspan="4">Lecturers from Experimental Condensed Matter and Applied Physics</td></tr>
<tr><td rowspan="2">Course details</td><td>Form</td><td>Credit hrs</td><td>CP</td><td>Examination</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4+2</td><td>9</td><td>PL</td></tr>
<tr><td>Frequency</td><td colspan="4">In general the course will be offered each SoSe.</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">
• Students are able to describe interaction forces at interfaces in terms of their range and their consequences on thermodynamic and kinetic properties.
• Students understand processes at surfaces like adsorption/desorption, surface 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.</td></tr>
<tr><td>Course content</td><td colspan="4">
• Surfaces and interface
• structure formation on surfaces
• self-assembly, morphology and transitions
• optical and electronic properties</td></tr>
<tr><td>Previous knowledge</td><td colspan="4">Experimental Physics I-IV</td></tr>
<tr><td rowspan="2">Work load (hours)</td><td>Course</td><td>Contact time</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>90 h</td><td>180 h</td><td>270 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Appl. Physics modules:
Advanced Experimental Physics (PL), Elective Subjects (SL)</td></tr>
<tr><td>Language</td><td colspan="4">English</td></tr>
</table>

3.1.5. Particle Detectors (9 ECTS)

Lecture 07LE33V-ADV_EXP_PDET	**Particle Detectors**			**9 ECTS**
Lecturer/s	Lecturers from Experimental Particle Physics			
Course details	**Type**	**Credit hrs**	**CP**	**Examination**
	Lecture and exercises (L+E)	4+2	9	SL or PL
Frequency	In general the course will be offered each WiSe			
Qualification objectives	• Students are able to understand the physics of particle detection • Students are able to understand the different types of particle detectors • Students are able to design a particle detector for specific experiments			
Course content	• 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			
Work load (hours)	**Course**	**Contact time**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Appl. Physics modules: Advanced Experimental Physics (PL), Elective Subjects (SL)			
Language	English			

3.2. Advanced Theoretical Physics (9 ECTS credit points)

Module 07LE33K-ADV_THEO	**Advanced Theoretical Physics**					**9 ECTS**
Responsibility	Dean of Studies, Lecturers for Theoretical Physics					
Courses		**Type**	**Credit hrs**	**CP**	**Exam-ina-tion**	**Term**
	Advanced Theoretical Physics	L+E	4+2	9	PL	WiSe+SoSe
	Total:			**9**		
Organization	A suitable lecture has to be selected by own choice from the list of Advanced Theoretical Physics lectures given below. Students have to register online for the final exam according to the announcements of the examination office.					
Module mark	The final module mark is the mark of the final written exam.					
Qualification objectives	• Students obtain advanced knowledge in particular field of modern 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.					
Work load (hours)	**Course**	**Contact time**	**Self-studies**	**Total**		
	Advanced Theoretical Physics	90 h	180 h	270 h		
	Total:	**90 h**	**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):

Course No.	Lecture	ECTS	Term		
			WiSe	SoSe	irregu-lar
07LE33V-ADV_THEO_QM	Advanced Quantum Mechanics	10	X		
07LE33V-ADV_THEO_CONDMAT	Theoretical Condensed Matter Physics	9		X	
07LE33V-ADV_THEO_CS	Classical Complex Systems	9	X		
07LE33V-ADV_THEO_OS	Complex Quantum Systems	9			X
07LE33V-ADV_THEO_QO	Quantum Optics	9			X
07LE33V-ADV_THEO_COMPPHYS	Computational Physics: Materials Science	9		X	

3.2.1. Advanced Quantum Mechanics (10 ECTS)

Lecture 07LE33V-ADV_QM	**Advanced Quantum Mechanics**				**10 ECTS**
Lecturer/s	Lecturers for Theoretical Physics				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examination**	**term**
	Lecture and exercises (L+E)	4+3	10	PL	WiSe
Frequency	The course will be offered each WiSe.				
Qualification objectives	• Students know the foundations of scattering theory and are able to apply these to problems involving simple potentials. • Students know the representations of the rotational group and their relevance for quantum theory. They have a fundamental 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 methods of Hartree- and Hartree-Fock and apply them to simple multi-particle systems. • Students know the fundamentals of time-dependent perturbation theory and can apply it to specific time-dependent problems. • Students know Dirac's equation and can solve it for the free case.				
Course content	• Scattering theory: scattering amplitude and cross-section, partial wave expansion, Lippmann-Schwinger equation and Born series. • Fundamentals of the representation theory of groups, in particular of the rotation group SO(3). Tensor product representations and irreducible representations. Wigner-Eckart theorem. Applications to angular momentum and spin couplings in atomic, molecular and condensed matter physics. • Time-dependent perturbation theory: Dyson-expansion, Fermi's Golden Rule, examples of application to important time-dependent quantum processes. • Many-particle systems: identical particles, spin-statistic theorem, variational principles, Hartree and Hartree-Fock approximations. • Interaction between radiation and matter. Quantization of the electromagnetic field. Interaction Hamiltonian, emission and absorption. • Relativistic quantum mechanics and quantum field theory; Dirac equation, quantization of Klein-Gordon and Dirac's equation.				

Previous knowledge	Theoretical Physics I-IV			
Work load (hours)	**Course**	**Contact time**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	105 h	195 h	300 h
Usability	M.Sc. Appl. Physics modules: Advanced Theoretical Physics (PL), Elective Subjects (SL)			
Language	English			

3.2.2. Theoretical Condensed Matter Physics (9 ECTS)

<table>
<tr><th>Lecture
07LE33V-
ADV_THEO_CONDMAT</th><th colspan="4">Theoretical Condensed Matter Physics</th><th>9 ECTS</th></tr>
<tr><td>Lecturer/s</td><td colspan="5">Lecturers from Theoretical Condensed Matter and Applied Physics</td></tr>
<tr><td rowspan="2">Course details</td><td colspan="2">Type</td><td>Credit hrs</td><td>CP</td><td>Examination</td></tr>
<tr><td colspan="2">Lecture and exercises (L+E)</td><td>4+2</td><td>9</td><td>PL</td></tr>
<tr><td>Frequency</td><td colspan="5">In general, the course will be offered each SoSe.</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">• 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.</td></tr>
<tr><td>Course content</td><td colspan="5">• 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.</td></tr>
<tr><td>Previous knowledge</td><td colspan="5">Experimental Physics I-IV, Theoretical Physics I-IV</td></tr>
<tr><td rowspan="2">Work load (hours)</td><td>Course</td><td colspan="2">Contact time</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td colspan="2">90 h</td><td>180 h</td><td>270 h</td></tr>
<tr><td>Usability</td><td colspan="5">M.Sc. Appl. Physics modules:
Advanced Theoretical Physics (PL), Elective Subjects (SL)</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
</table>

3.2.3. Classical Complex Systems (9 ECTS)

<table>
<tr><td>Lecture
07LE33V-
ADV_THEO_CS</td><td colspan="4">Classical Complex Systems 9 ECTS</td></tr>
<tr><td>Lecturer/s</td><td colspan="4">Lecturers from Theoretical Atomic, Molecular and Optical Sciences
or from Theoretical Condensed Matter and Applied Physics</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>CP</td><td>Examination</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4+2</td><td>9</td><td>PL</td></tr>
<tr><td>Frequency</td><td colspan="4">In general the course will be offered each WiSe.</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">• Students are familiar with stochastic and deterministic concepts to model complex systems.
• Students are capable of recognizing and rigorously describing phenomena commonly encountered in complex systems.
• Students are able to use probabilistic notions to model systems subject to uncertainty about their microscopic states and laws.
• Students are able to run and interpret Monte Carlo computer simulations as well as to quantify the confidence in results produced by randomized algorithms.
• Students are able to use basic statistical tools to infer probabilistic statements from empirical observations.</td></tr>
<tr><td>Course content</td><td colspan="4">The first two thirds of the lecture cover basic theory, while the final third is concerned with concrete applications. Topics treated in the latter part depend more strongly on the lecturer.

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

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

Applications:

Molecular dynamics simulations
• Molecular driving forces and force field models
• Simulation techniques and sampling
• Energy landscapes and analysis of dynamics</td></tr>
</table>

	Time series analysis and inverse problems • Estimation and test theory • Spectral analysis • State space model			
Previous knowledge	Theoretical Physics I-V			
Work load (hours)	**Course**	**Contact time**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Appl. Physics modules: Advanced Theoretical Physics (PL), Elective Subjects (SL)			
Language	English			

3.2.4. Complex Quantum Systems (9 ECTS)

Lecture 07LE33V-ADV_THEO_OS	**Complex Quantum Systems**			**9 ECTS**
Lecturer/s	Lecturers from Theoretical Atomic, Molecular and Optical Sciences or from Theoretical Condensed Matter and Applied Physics			
Course details	**Type**	**Credit hrs**	**CP**	**Examination**
	Lecture and exercises (L+E)	4+2	9	PL
Frequency	Lecture is offered on an irregular basis.			
Qualification objectives	• 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	• Quantum states: Pure and mixed states, density matrices, quantum state space • Composite quantum systems: Tensor product, entangled states, partial trace and reduced density matrix, quantum entropy • Open quantum systems: Closed and open systems, dynamical maps, quantum operations, complete positivity and Kraus representation • Dynamical semigroups and quantum master equations: Semigroups and generators, quantum Markovian master equations, Lindblad theorem • General properties of the master equation: Dynamics of populations and coherences, Pauli master equation, relaxation to equilibrium • Decoherence: Destruction of quantum coherence through interaction with an environment, decoherence versus relaxation Applied Track: • Microscopic theory: System-reservoir models, Born-Markov approximation, microscopic derivation of the master equation. • Applications: Quantum theory of the laser, superradiance, quantum transport, quantum Boltzmann equation Structural Track: • Uncertainty relations: Joint measurability, uncertainty relations for continuous and discrete observables, information-disturbance trade-off			

	• Contextuality: Non-Locality, Bell's Theorem, Marginals			
Previous knowledge	Theoretical Physics IV (Quantum Mechanics) and Advanced Quantum Mechanics			
Work load (hours)	**Course**	**Contact time**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Appl. Physics modules: Advanced Theoretical Physics (PL), Elective Subjects (SL)			
Language	English			

3.2.5. Quantum Optics (9 ECTS)

<table>
<tr><td colspan="1">Lecture
07LE33V-
ADV_THEO_QO</td><td colspan="4">Quantum Optics 9 ECTS</td></tr>
<tr><td>Lecturer/s</td><td colspan="4">Lecturers from Theoretical Atomic, Molecular and Optical Physics</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>CP</td><td>Examination</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4+2</td><td>9</td><td>PL</td></tr>
<tr><td>Frequency</td><td colspan="4">Lecture is offered on an irregular basis.</td></tr>
<tr><td>Qualification objectives</td><td colspan="4">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 set-tings to probe generic quantum properties of the light field</td></tr>
<tr><td>Course content</td><td colspan="4">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</td></tr>
<tr><td>Previous knowledge</td><td colspan="4">Experimental Physics I-IV, Theoretical Physics I-IV</td></tr>
<tr><td rowspan="2">Work load (hours)</td><td>Course</td><td>Contact time</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>90 h</td><td>180 h</td><td>270 h</td></tr>
<tr><td>Usability</td><td colspan="4">M.Sc. Appl. Physics modules:
Advanced Theoretical Physics (PL), Elective Subjects (SL)</td></tr>
</table>

Language	English

3.2.6. Computational Physics: Materials Science (9 ECTS)

Lecture 07LE33V-ADV_THEO_COMPPHYS	**Computational Physics: Materials Science**			**9 ECTS**
Lecturer/s	Prof. Dr. Michael Moseler			
Course details	**Type**	**Credit hrs**	**CP**	**Examination**
	Lecture and exercises (L+E)	4+2	9	PL
Frequency	The lecture is offered regularly in the summer semester.			
Qualification objectives	• 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	This lecture provides an introduction into basic concepts of atomistic computational materials science. The computational tools for different time and length scales will be introduced and it will be discussed how these tools can be combined in order to solve physical problems extending over too many scales for one single method alone. We will start with a brief introduction to density functional theory and more approximate methods such as tight binding. Quantum derived forces can be extracted from these methods and the short term dynamics of small nanosystems can be studied. For the simulation of larger systems and longer time scales, classical interatomic potentials are required. The students will become familiar with some examples for the different types of interatomic potentials: e.g. Lennard-Jones, Born-Mayer, Embedded-Atom, Bond-Order-potentials as well as bead-spring potentials for polymers. A brief introduction into the basic methodology of micro-canonical and thermostated molecular dynamics simulations will be given. The lecture is accompanied by a hands-on programming course. Classical molecular dynamics simulations will be used to study metallic and covalently bonded materials			
Literature	• lecture script: A brief Introduction into Computational Materials Science			

Previous knowledge	Basic knowledge in classical and quantum mechanics			
Work load (hours)	**Course**	**Contact time**	**Self-studies**	**Total**
	Lecture and exercises (L+E)	90 h	180 h	270 h
Usability	M.Sc. Appl. Physics modules: Advanced Theoretical Physics (PL), Applied Physics (PL or SL), Elective Subjects (SL)			
Language	English			

3.3. Applied Physics (18 ECTS credit points)

<table>
<tr><th>Module
07LE33K-APHYS</th><th colspan="6">Applied Physics 18 ECTS</th></tr>
<tr><td>Responsibility</td><td colspan="6">Dean of Studies,
Lecturers of the Institute of Physics and associated Institutes</td></tr>
<tr><td rowspan="3">Courses</td><td></td><td>Type</td><td>Credit hrs</td><td>CP</td><td>Exam-ination</td><td>Term</td></tr>
<tr><td>Applied Physics lectures by own choice</td><td>L+E</td><td>According to selected courses</td><td>18</td><td>PL</td><td>WiSe+SoSe</td></tr>
<tr><td>Total:</td><td></td><td></td><td>18</td><td></td><td></td></tr>
<tr><td>Organization</td><td colspan="6">Students select different lectures by own choice in order collect at least 18 ECTS credits in total from the list of Applied Physics lectures given below.
For the marked assessment, students take an oral exam (~30 minutes) on the content of lectures containing at least 9 ECTS credit points. Students have to select their examiner and register for the final exams according to the announcements of the examination office.</td></tr>
<tr><td>Module mark</td><td colspan="6">The final module mark is the mark of the oral exam.</td></tr>
<tr><td>Qualification objectives</td><td colspan="6">The qualification objects are subject to the selected course and are listed in the individual course descriptions.</td></tr>
<tr><td>Course content</td><td colspan="6">A range of Applied Physics lectures is offered on a regular or irregular basis. The specific content of each lecture is detailed in the individual course descriptions.</td></tr>
<tr><td rowspan="3">Work load (hours)</td><td colspan="2">Course</td><td colspan="2">Contact time</td><td>Self-studies</td><td>Total</td></tr>
<tr><td colspan="2">Applied Physics lectures</td><td colspan="3">subject to selected lectures</td><td>540 h</td></tr>
<tr><td colspan="2">Total:</td><td colspan="3"></td><td>540 h</td></tr>
<tr><td>Usability</td><td colspan="6">M.Sc. Applied Physics</td></tr>
<tr><td>Previous knowledge</td><td colspan="6">Specific prerequisites are given in the individual course descriptions.</td></tr>
<tr><td>Language</td><td colspan="6">English</td></tr>
</table>

List of eligible lectures (Module: Applied Physics):

Course No.	Lecture	ECTS	Term		
			WiSe	SoSe	irregu-lar
07LE33V-LTPHYS	Low Temperature Physics	9			X
07LE33V-SELFAS	Physical Processes of Self-Assembly and Pattern Formation	7		X	
07LE33V-POL	Experimental Polymer Physics	9	X		
07LE33V-	Matter on Surfaces	9			X
07LE33V-	Statistics and Numerics	7			X
07LE33V-	Dynamic Systems in Biology	7			X
07LE33V-MOLDYN	Molecular Dynamics & Spectroscopy	7			X
11LE50V-5901	Photonic Microscopy	7	X		
11LE50V-5219	Optical Trapping and Particle-Tracking	7		X	
11LE50V-5305	Biophysics of the Cell	7	X		
11LE50V-5221	Wave Optics	7		X	
07LE33V-PHYSMED	Physics of Medical Imaging Methods	5	X		
07LE33V-CARDI	Biophysics of cardiac function and signals	5	X		
07LE33V-LASESPEC	Laser-based Spectroscopy and Analytical Methods	5		X	
07LE33V-XRAY	X-Ray Analysis - Applications in Material and Life Sciences	5			X
07LE33V-PHOTOVOLT	Photovoltaic Energy Conversion	5		X	
07LE33V-HL	Fundamentals of Semiconductors & Optoelectronics	5	X		
11LE50V-5115	Mechanical Properties and Degredation Mechanisms	3		X	
07LE33V-MODMAT	Theory and Modeling of Materials	5	X	X	
07LE33V-COMPPHYS	Computational Physics: Density Functional Theory	7			X
07LE33V-QTRANS	Quantum Transport	7		X	
11LE50MO-2080	Modeling and System Identification	6	X		
09LE03V-SP2-04_0003	Computational Neuroscience: Models of Neurons and Networks	7		X	
09LE03V-SP2-04_0004	Computational Neuroscience: Simulation of Biological Neuronal Networks	5		X	
07LE33V-SOLPHYS	Solar Physics	5	(X)		
07LE33V-ASTRINST	Modern Astronomical Instrumentation	5	(X)		
07LE33V-ASTROLAB	Lab Course in Astrophysics	5		X	

3.3.1. Low Temperature Physics (9 ECTS)

<table>
<tr><th>Lecture
07LE33V-LTPHYS</th><th colspan="5">Low Temperature Physics 9 ECTS</th></tr>
<tr><td>Lecturer/s</td><td colspan="5">Prof. Dr. Frank Stienkemeier</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Examina-tion</td><td>term</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4 + 2</td><td>9</td><td>SL or PL</td><td>WiSe or SoSe</td></tr>
<tr><td>Frequency</td><td colspan="5">The lecture is offered irregularly</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">• 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</td></tr>
<tr><td>Course content</td><td colspan="5">• 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</td></tr>
<tr><td>Literature</td><td colspan="5">• 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)</td></tr>
</table>

Preliminaries / Previous knowledge	Experimental Physics I-IV Quantum Mechanics		
Final Exam	Written or oral exam (120 min)		
Language	English		
Work load (hours)	Contact time	Self-studies	Total
	90 h	180	270

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

Lecture 07LE33V-SELFAS	**Physical Processes of Self-Assembly and Pattern Formation**				**7 ECTS**
Lecturer/s	Prof. Dr. Günter Reiter				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L+E)	3 + 2	7	SL or PL	SoSe
Frequency	The lecture is offered in the summer semester				
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	Goal: Questions about how organization and order in various systems arises have been raised since ancient times. Self-assembling processes are common throughout nature and technology. The ability of molecules and objects to self-assemble into supra-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. Preliminary program: "Physical laws for making compromises" Self-assembly is governed by (intermolecular) interactions between pre-existing parts or disordered components of a system. The final (desired) structure is 'encoded' in the shape and properties of the basic building blocks. In this course, we will discuss general rules about growth and evolution of structures and patterns as well as methods that predict changes in organization due to changes made to the underlying components and/or the environment.				
Literature	• Yoon S. LEE, Self-Assembly and Nanotechnology:A Force Balance Approach, Wiley 2008 • Robert KELSALL, Ian W. HAMLEY, Mark GEOGHEGAN, Nanoscale Science and Technology, Wiley, 2005 • Richard A.L. JONES, Soft Machines: Nanotechnology and Life, Oxford University Press, USA 2008				

	• Philip BALL, Shapes, Flow, Branches. Nature's Patterns: A Tapestry in Three Parts, Oxford University Press, USA • J.N. ISRAELACHVILI, Intermolecular and Surface Forces, Third Edition, Elsevier, 2011 • Continuative and supplementary references will be given during the lecture.		
Preliminaries / Previous knowledge	Experimentalphysik IV (Condensed Matter)		
Final Exam	Written or oral exam (120 min)		
Language	English		
Work load (hours)	Contact time	Self-studies	Total
	75 h	135	210

3.3.3. Experimental Polymer Physics (9 ECTS)

<table>
<tr><td>Lecture
07LE33V-POL</td><td colspan="5">Experimental Polymer Physics 9 ECTS</td></tr>
<tr><td>Lecturer/s</td><td colspan="5">Prof. Dr. Günter Reiter</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Examina-tion</td><td>term</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4 + 2</td><td>9</td><td>SL or PL</td><td>WiSe</td></tr>
<tr><td>Frequency</td><td colspan="5">The lecture is offered in the winter semester</td></tr>
<tr><td>Qualification objectives</td><td colspan="5"></td></tr>
<tr><td>Course content</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">• G. Strobl, The Physics of Polymers
• Colby & Rubinstein, Polymer Physics</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="5">Thermodynamics</td></tr>
<tr><td>Final Exam</td><td colspan="5">Written or oral exam (120 min)</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td rowspan="2">Work load (hours)</td><td colspan="2">Contact time</td><td colspan="2">Self-studies</td><td>Total</td></tr>
<tr><td colspan="2">90 h</td><td colspan="2">180</td><td>270</td></tr>
</table>

3.3.4. Matter on Surfaces (9 ECTS)

<table>
<tr><td rowspan="1">Lecture
07LE33V-</td><td colspan="5">Matter on Surfaces 9 ECTS</td></tr>
<tr><td>Lecturer/s</td><td colspan="5">Prof. Dr. Günter Reiter</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Examina-tion</td><td>term</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>4 + 2</td><td>9</td><td>SL or PL</td><td>SoSe or WiSe</td></tr>
<tr><td>Frequency</td><td colspan="5">The lecture is offered irregularly</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">Students will get an overview over phenomena, which only appear on surfaces and interfaces (e.g. how to make water running uphill?). The course deals with special structural and electronic properties of liquid and solid surfaces as well as their relevance in many fields of modern material science and nano-technology.</td></tr>
<tr><td>Course content</td><td colspan="5">Surfaces between solids and liquids can be found in most of the physical, chemical, biological and geological systems, as well as in many technological processes. Although the number of atoms or molecules at these surfaces is comparatively small, this "minority" can often dominate or even control the behavior of large (macroscopic) systems.

Topics:
1. General description of interfaces: Thermodynamics and kinetics
2. Interaction forces at interfaces: Short- and long range forces , ...
3. Liquids and liquid interfaces: Droplets, bubbles, waves, "liquid beads"
4. Solid-liquid interfaces: Hydrodynamics, capillarity, wetting,...
5. Structure of solid surfaces: Electronic processes at surfaces
6. Surface processes: Adsorption/desorption, phase transitions
7. Making of well defined solid surfaces: Surface reconstruction, surface transport,...
8. Growth- and decay: Epitaxy, nucleation, lattice mismatches, mechanical stress
9. Organic layers and nanostructures on surfaces: Directed structuring of surfaces at nm-scale</td></tr>
<tr><td>Literature</td><td colspan="5">• Intermolecular and Surface Forces, With Applications to Colloidal and Biological Systems, Jacob Israelachvili, Academic Press 1995 bzw. Elsevier 2008
• "Capillarity and Wetting Phenomena: Drops, Bubbles, Pearls, Waves" von P.-G. de Gennes, F. Brochard-Wyart und D. Quéré, Springer, New York, 2004
• John A. Venables, Lecture notes on Surfaces and Thin Films</td></tr>
</table>

	• I. Markov, Crystal Growth for Beginners, World Scientific • Continuative and supplementary references will be given during the lecture.		
Preliminaries / Previous knowledge	Experimentalphysik IV (Condensed Matter)		
Final Exam	Written or oral exam (120 min)		
Language	English		
Work load (hours)	Contact time	Self-studies	Total
	90 h	180	270

3.3.5. Statistics and Numerics (7 ECTS)

Lecture 07LE33V-	**Statistics and Numerics**				**7 ECTS**
Lecturer/s	Prof. Dr. Jens Timmer				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L+E)	3 + 2	7	SL or PL	SoSe or WiSe
Frequency	The lecture is offered irregularly				
Qualification objectives	• Students are familiar with the basic concepts of statistical reasoning. • Students are able to mathematically formulate statistical and numerical problems. • Students can implement computer programs to solve statistical and numerical problems.				
Course content	• Random variables • Parameter estimation • Test theory • Solution of systems of linear equations • Optimization • Non-linear modeling • Kernel estimator • Integration of ordinary, partial and stochastic differential equations • Spectral analysis • Markov Chain Monte Carlo procedures				
Literature	• Press et al. Numerical Recipes, Cambridge University Press				
Preliminaries / Previous knowledge	Basics of Analysis and Linear Algebra				
Final Exam	Written or oral exam (120 min)				
Language	English				
Work load (hours)	Contact time	Self-studies	Total		
	75 h	135	210		

3.3.6. Dynamic Systems in Biology (7 ECTS)

Lecture 07LE33V-	**Dynamic Systems in Biology**				**7 ECTS**
Lecturer/s	Prof. Dr. Jens Timmer				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L+E)	3 + 2	7	SL or PL	SoSe or WiSe
Frequency	The lecture is offered irregularly				
Qualification objectives	• 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	• Numerical integration of differential equations • Mathematical biology • Population models • Hodgkin-Huxley model • Turing model • Enzyme kinetics • Systems biology • Metabolism • Signal transduction • Gene regulation				
Literature	• J.D. Murray. Mathematical Biology, Springer				
Preliminaries / Previous knowledge	Basics of Analysis and Linear Algebra				
Final Exam	Written or oral exam (120 min)				
Language	English				
Work load (hours)	Contact time	Self-studies	Total		
	75 h	135	210		

3.3.7. Molecular Dynamics & Spectroscopy (7 ECTS)

Lecture 07LE33V-MOLDYN	**Molecular Dynamics & Spectroscopy**				**7 ECTS**
Lecturer/s	Prof. Dr. Gerhard Stock				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L+E)	3 + 2	7	SL or PL	SoSe or WiSe
Frequency	The lecture is offered irregularly				
Qualification objectives	• Students are able to ... • Students are familiar with ...				
Course content	• Time-Dependent Quantum Dynamics • Density Matrix Theory • Quantum-Classical Formulation • Linear Spectroscopy • Nonlinear Techniques • Multidimensional Spectroscopy				
Literature	• P. Hamm, M. Zanni, Concepts and Methods of 2D Infrared Spectroscopy, Cambridge University Press, 2011 • V. May, O. Kühn, Charge and Energy Transfer Dynamics in Molecular Systems, Wiley-VCH, 2004 • S. Mukamel, Principles of Nonlinear Optical Spectroscopy, Oxford University Press, 1995				
Preliminaries / Previous knowledge					
Final Exam	Written or oral exam (120 min)				
Language	English				
Work load (hours)	Contact time	Self-studies	Total		
	75 h	135	210		

3.3.8. Photonic Microscopy (7 ECTS)

Lecture 11LE50V-5901	**Photonic Microscopy**				**7 ECTS**
Lecturer/s	Prof. Dr. Alexander Rohrbach				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L+E)	3 + 2	7	SL or PL	WiSe
Frequency	The lecture is offered in the winter semester				
Qualification objectives	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 experience that wave diffraction is not reducing the information and how to circumvent the optical resolution limit. The student should learn to distinguish between coherent and incoherent imaging, learn about modern techniques using self-reconstructing laser beams, two photon excitation, fluorophores depletion through stimulated emission (STED) or multi-wave mixing by coherent anti-Stokes Raman scattering (CPLS). The tutorials help the student to get a more in depth and thorough 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 exercise and present them during the tutorial. Only difficult exercises are presented by the tutors.				
Course content	The scientific breakthroughs and technological developments in optical microscopy and imaging have experienced a real revolution over the last 10-15 years. Hence, the 2014 Nobel-Prize for super-resolution microscopy could be seen as a logical consequence. This lecture gives an overview about physical principles and techniques used in modern photonic imaging. Topics: 1. Microscopy: History, Presence and Future 2. Wave- and Fourier-Optics 3. Three-dimensional optical imaging and information transfer 4. Contrast enhancement by Fourier-filtering 5. Fluorescence – Basics and techniques 6. Point scanning and confocal microscopy 7. Microscopy with self-reconstructing beams 8. Optical tomography 9. Nearfield and Evanescent Field Microscopy 10. Super-resolution using structured illumination 11. Multi-Photon-Microscopy				

<table>
<tr><td></td><td colspan="3">12. Super resolution imaging by switching single molecules

The lecture has an ongoing emphasis on applications, but nevertheless presents a mixture of fundamental physics, compact mathematical descriptions and many examples and illustrations. The lecture aims to encompass the current state of a scientific field, which will influence the fields of nanotechnology and biology/medicine quite significantly.</td></tr>
<tr><td>Literature</td><td colspan="3">Accompanying to the lecture printed lecture notes with defined gaps (white boxes) are distributed.

Optical Microscopy:
Jerome Mertz: Introduction to Optical Microscopy, Roberts & Co Publ. 2009
U. Kubitschek, Fluorescence Microscopy, Wiley-Blackwell 2013
Min Gu, Advanced optical imaging theory, Springer - Berlin, 1999
James B. Pawley: Handbook of Biological Confocal Microscopy , Springer - Berlin, 2006
Herbert Gross: Handbook of optical systems, Vol 2: Physical image formation, Wiley VCH 2005
General Optics:
Hecht, E. (2002). Optics, Addison Wesley.
Saleh, B. E. A. and M. C. Teich (1991). Fundamentals of Photonics, Wiley & Sons,Inc.
Herbert Gross: Handbook of optical systems, Vol 1-5</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="3"></td></tr>
<tr><td>Final Exam</td><td colspan="3">Written or oral exam (120 min)</td></tr>
<tr><td>Language</td><td colspan="3">English</td></tr>
<tr><td rowspan="2">Work load (hours)</td><td>Contact time</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>75 h</td><td>135</td><td>210</td></tr>
</table>

3.3.9. Optical Trapping and Particle-Tracking (7 ECTS)

Lecture 11LE50V-5219	**Optical Trapping and Particle-Tracking**				**7 ECTS**
Lecturer/s	Prof. Dr. Alexander Rohrbach				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L+E)	3 + 2	7	SL or PL	SoSe
Frequency	The lecture is offered in the summer semester				
Qualification objectives	Optical traps and optical micro-manipulation techniques do have the potential to play a key role in future micro- and nano-systems in conjunction with the life sciences. In this lecture the students should learn what is doable with optical forces, where physical limits are and what is limited by nowadays technology. Besides fascinating fundamental research various applications related to biology or fluctuation based systems are presented. The lecture is manifold and teaches basics in optics, statistical physics and biology/biophysics. The tutorials help the students to get a more in depth and thorough 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 exercise and present them during the tutorial. Only difficult exercises are presented by the tutors.				
Course content	1. Introduction 2. Light - Information carrier and actor 3. About microscopy 4. Light scattering 5. Optical forces 6. Tracking beyond the uncertainty 7. Brownian motion and calibration techniques 8. Photonic force microscopy 9. Applications in cell biophysics 10. Time-multiplexing and holographics optical traps 11. Applications in microsystems technology 12. Applications in nanotechnology				
Literature	Accompanying to the lecture printed lecture notes with defined gaps (white boxes) are distributed. General optics: • Hecht, E. (2002). Optics, Addison Wesley. • Saleh, B. E. A. and M. C. Teich (1991). Fundamentals of Photonics, Wiley & Sons, Inc.				

<table>
<tr><td></td><td colspan="3">Nano optics
• L. Novotny & B. Hecht, E. (2002). Principles of Optics, Cambridge.

Statistical physics and thermodynamics
• Standard text books

Chemical and biological forces and interactions
• Leckband, D. & J. Israelachvili (2001). "Intermolecular forces in biology." Quart. Rev. Biophys 34: 105–267</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="3"></td></tr>
<tr><td>Final Exam</td><td colspan="3">Written or oral exam (120 min)</td></tr>
<tr><td>Language</td><td colspan="3">English</td></tr>
<tr><td rowspan="2">Work load (hours)</td><td>Contact time</td><td>Self-studies</td><td>Total</td></tr>
<tr><td>75 h</td><td>135</td><td>210</td></tr>
</table>

3.3.10. Biophysics of the Cell (7 ECTS)

<table>
<tr><td>Lecture
11LE50V-5305</td><td colspan="5">Biophysics of the Cell 7 ECTS</td></tr>
<tr><td>Lecturer/s</td><td colspan="5">Prof. Dr. Alexander Rohrbach</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Examina-tion</td><td>term</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>3 + 2</td><td>7</td><td>SL or PL</td><td>WiSe</td></tr>
<tr><td>Frequency</td><td colspan="5">The lecture is offered in the winter semester</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">This lecture gives a survey through modern cell biophysics, addresses state of the art scientific questions and presents modern investigation methods. This comprises classical but also novel physical methods and theories, which pushed the field of biophysics together with newest measurement technology. The applied physical methods do not only inspire biology and medicine, but also the physics of complex systems, which achieves an unequalled level of self-organisation and complexity inside living cells. This lecture is designed for physicists and engineers and provides a colourful mixture of physics, biology, chemistry, mathematics, and engineering that is illustrated with numerous pictures and animations.
The tutorials help the students 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 exercise and present them during the tutorial. Only difficult exercises are presented by the tutors.</td></tr>
<tr><td>Course content</td><td colspan="5">1. Structure of the cell or the recipe for cell-biophysical science
2. Diffusion and Fluctuation
3. Sensing and Acting measurement principles
4. Biologically relevant forces
5. Biophysics of proteins
6. Polymer physics
7. Visco-elasticity and micro-rheology
8. Dynamics of the cytoskeleton
9. Molecular motors
10. Membrane biophysics</td></tr>
<tr><td>Literature</td><td colspan="5">Accompanying to the lecture printed lecture notes with defined gaps (white boxes) are distributed.

• Rob Phillips: Physical Biology of the Cell
• Joe Howard: Mechanics of Motor Proteins and the Cytoskeleton
• Gary Boal: Mechanics of the Cell
• Erich Sackmann & Rudolf Merkel: Lehrbuch der Biophysik</td></tr>
</table>

Preliminaries / Previous knowledge			
Final Exam	Written or oral exam (120 min)		
Language	English		
Work load (hours)	Contact time	Self-studies	Total
	75 h	135	210

3.3.11. Wave Optics (7 ECTS)

Lecture 11LE50V-5221	**Wave Optics**				**7 ECTS**
Lecturer/s	Prof. Dr. Alexander Rohrbach				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L+E)	3 + 2	7	SL or PL	SoSe
Frequency	The lecture is offered in the summer semester				
Qualification objectives	The goal of this lecture is to teach the students how light interacts with small structures and how optical systems guide light. The students will start at Maxwell's equations and move on to the description of light as photon or wave, depending on the given problem. Furthermore, the close connection between spatial and temporal coherence, interference and holography is demonstrated. The last chapter teaches concepts of linear and non-linear light scattering, as well as the most important plasmonic effects. In total, the students learn how to shape light in three dimensions and how optical problems that arise in research and development are solved.				
Course content	1. Introduction Some motivation, literature and a bit of history 2. From Electromagnetic Theory to Optics What is light? Which illustrative pictures do the Maxwell equations provide? If matter, dielectric and metallic, consists of coupled, damped springs (harmonic oscillators), how does matter depend on the frequency of light? What do the wave equation and the Helmholtz equation express and how can one handle waves in position space and frequency space. 3. Fourier-Optics How does a wave transform position information into directional information? Why can this be well described by Fourier transformations in 1D, 2D and 3D? What has this to do with linear optical system theory including spatial frequency filters and the sampling theorem? 4. Wave-optical Light Propagation and Diffraction Different methods are introduced of how to describe the propagation of ways in position space and frequency space. We do the direct transfer from propagation to diffraction of light and momentum space. We treat evanescent waves, thin diffracted objects, the propagation of light in inhomogeneous media and the diffraction at gratings. This allows to discuss important active elements such as acousto-optic and spatial light modulators. We end with adaptive optics and phase conjugation.				

	5. Interference, Coherence and Holography We learn how a composition of k-vectors defines the phases of interfering waves and the resulting stripe patterns. The relative phases of each partial wave in space and time change the interference significantly and define the coherence of light - these concepts will be discussed in detail. We learn how to write and read phase information in holography. 6. Light Scattering and Plasmonics The interaction of light with matter is based on particle scattering: we discuss the theoretical concepts of light scattering on the background of Fourier theory. We expend these approaches to photon diffusion, nonlinear optics, fluorescence and Raman scattering or scattering at semiconductor quantum dots - which are all hot topics in modern Photonics. A big emphasis is put on the description of surface plasmons and particle plasmons, where light can be extremely confined. 1. Introduction 1.1. Motivation 1.2. Literature 1.3. A bit of history 2. From Electromagnetic Theory to Optics 2.1. What is Light? 2.2. The Maxwell-equations 2.3. The change of Light in Matter 2.4. Wave equation and Helmholtz equation 2.5. Waves in position space and frequency space 3. Fourier-Optics 3.1. Introduction 3.2. The Fourier-Transformation 3.3. Linear Optical Systems 3.4. Spatial frequency filters 3.5. The Sampling Theorem 4. Wave-optical Light Propagation and Diffraction 4.1. Paraxial light propagation by Gaussian beams 4.2. Wave Propagation and Diffraction 4.3. Evanescent waves 4.4. Diffraction at thin Phase and Amplitude Objects 4.5. Light Propagation in inhomogeneous Media 4.6. Diffraction at gratings 4.7. Acousto-Optics 4.8. Spatial Light Modulators 4.9. Adaptive Optics and Phase Conjugation 5. Interference, coherence and holography 5.1. Some Basics 5.2. Interferometry 5.3. Foundations of Coherence Theory 5.4. Principles of Holography 6. Light Scattering and Plasmonics 6.1. Scattering of light at particles 6.2. Photon Diffusion

	6.3. Basics of Nonlinear Optics 6.4. Fluorescence und Raman-scattering 6.5. Fluorescing quantum dots 6.6. Surface Plasmons and Particle Plasmons		
Literature	Accompanying to the lecture printed lecture notes with defined gaps (white boxes) are distributed.		
Preliminaries / Previous knowledge			
Final Exam	Written or oral exam (120 min)		
Language	English		
Work load (hours)	Contact time	Self-studies	Total
	75 h	135	210

3.3.12. Physics of Medical Imaging Methods (5 ECTS)

<table>
<tr><th>Lecture
07LE33V-PHYSMED</th><th colspan="5">Physics of Medical Imaging Methods 5 ECTS</th></tr>
<tr><td>Lecturer/s</td><td colspan="5">Prof. Dr. Michael Bock (Universitäts Klinikum)</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Examina-tion</td><td>term</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>2 + 1</td><td>5</td><td>SL or PL</td><td>WiSe</td></tr>
<tr><td>Frequency</td><td colspan="5">The lecture is offered regularly in the winter semester.</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">• 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</td></tr>
<tr><td>Course content</td><td colspan="5">Medical imaging is becoming increasingly important in the detection of disease, in the management of the patients, and in the monitoring of a therapy. In this lecture the physical basics of different medical imaging technologies will be presented, and different clinical application scenarios will be discussed. The following topics will be addressed:
• overview over the physics of medical imaging
• Magnetic Resonance Imaging (MRI)
o magnetisation, Bloch equations, relaxation times T1 and T2
o spin gymnastics and image contrast
o magnets, gradients and radio-frequency coils
o quantitative MRI
o functional MRI, flow, diffusion, perfusion measurements
• Nuclear Medicine
o principles of radio-tracer detection
o scintigraphy
o single photon emission computed tomography (SPECT)
o positron emission tomography (PET)
• ultrasound (US)
o sound generation and propagation in tissue
o US imaging
o Doppler US
o therapeutic applications of US (Lithotrypsy)
• X-ray Imaging
o properties and generation of X-rays
o fluoroscopy
o computed tomography
o image reconstruction from projections
• role of medical imaging in</td></tr>
</table>

	o the detection of disease o in patient management o therapy monitoring		
Literature	• Oppelt A: Imaging Systems for Medical Diagnostics • Dössel O: Bildgebende Verfahren in der Medizin: Von der Technik zur medizinischen Anwendung		
Preliminaries / Previous knowledge			
Final Exam	Written or oral exam (120 min)		
Language	English		
Work load (hours)	Contact time	Self-studies	Total
	45 h	105	150

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

Course 07LE33V-CARDI	**Biophysics of cardiac function and signals**				**5 ECTS**
Lecturer/s	Dr. Gunnar Seemann, Prof. Dr. Peter Kohl, Dr. Franziska Schneider (Faculty of Medicine, Institute for Experimental Cardiovascular Medicine)				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L+E)	2 + 1	5	CA or AR	WiSe
Frequency	The course is offered in the winter semester				
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	• 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	• lecture slides				
Preliminaries / Previous knowledge	Basic interest in biology and computational modelling. Knowledge in Matlab or Python are beneficial				
Final Exam	Oral exam (30 min)				
Language	English				
Work load (hours)	Contact time	Self-studies	Total		
	45 h	105 h	150 h		

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

Lecture 07LE33V-LASESPEC	**Laser-based Spectroscopy and Analytical Methods**				**5 ECTS**
Lecturer/s	Dr. Frank Kühnemann (Fraunhofer IPM)				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L+E)	2 + 1	5	SL or PL	SoSe
Frequency	The lecture is offered regularly in the summer semester.				
Qualification objectives	At the end of the course, the students • Will have knowledge about laser-based spectroscopic methods, particularly with respect to analytical applications. • Will understand the physical principles of tuneable laser operation. • Will be enabled to evaluate the fundamental and practical limitations of detection techniques. • Will have insight into development processes necessary to transfer a scientific method into a practical tool for industrial environments. • Will be trained in the preparation and presentation of scientific talks.				
Course content	Lasers did become a powerful tool for measurement applications in areas like industry, medicine, or environment. The current course focuses on the use of tuneable lasers to interrogate the spectral "fingerprints" of gases, liquids and solids for analytical purposes. Typical examples are air quality monitoring or process control in industry. The **lecture** block in the first half of the course will give a comprehensive introduction into the following topics • Infrared molecular spectra • Tuneable lasers • Spectroscopic techniques (absorption, photoacoustic spectroscopy, cavity-based methods) • Background signals, noise and detection limits The **seminar** talks in the second block will focus on the application of different spectroscopic methods for analytical tasks. At the start of the course, students will choose from a list of provided topics to prepare a talk and a short written summary. The preparation will be supported by topical literature and discussion sessions with the course staff. Duration of the talks will be appr. 30 minutes, followed by a discussion of content and presentation style.				
Literature	• lecture script				

	• recommended literature will be announced in the lecture		
Preliminaries / Previous knowledge	Advanced Optics and Lasers		
Final Exam	Oral (graded seminar talk) and written (talk summary)		
Language	English		
Work load (hours)	Contact time	Self-studies	Total
	45 h	105	150

3.3.15. X-Ray Analysis – Applications in Material and Life Sciences (5 ECTS)

Lecture 07LE33V-XRAY	**X-Ray Analysis** **- Applications in Material and Life Sciences** **5 ECTS**				
Lecturer/s	Prof. Dr. Alex Ulyanenkov (Atomicus GmbH)				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture (L)	2	5	CA or AR	SoSe
Frequency	The lecture is offered irregularly in the winter semester.				
Qualification objectives	• Students know the basics of crystallography and electromagnetic scattering; • Students are familiar in general with the modern nano-technologies including new materials design, semiconductor devices, mechanical and physical properties of surfaces and bulk materials, which are the subject of X-ray analysis				
Course content	• Fundamentals of X-ray scattering from crystallographic and structureless materials • X-ray instrumentation and equipment • Theories of X-ray scattering • X-ray methods and techniques used in research and industry • Applications of X-ray analysis • Software for interpretation of X-ray data				
Literature	• Lectures PowerPoint presentations • A.Benediktovitch, I.Feranchuk, A.Ulyanenkov, Theoretical Concepts of X-ray Nanoscale Analysis, Heidelberg: Springer, 2013				
Preliminaries / Previous knowledge	Basic knowledge of quantum physics and materials physics is helpful but not mandatory				
Final Exam	Written or oral exam (120 min)				
Language	English				
Work load (hours)	Contact time	Self-studies	Total		
	30 h	120	150		

3.3.16. Photovoltaic Energy Conversion (5 ECTS)

Lecture 07LE33V-PHOTOVOLT	**Photovoltaic Energy Conversion**				**5 ECTS**
Lecturer/s	Dr. Uli Würfel (Fraunhofer ISE)				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L+E)	2 + 1	5	SL or PL	SoSe
Frequency	The lecture is offered regularly in the summer semester.				
Qualification objectives	• 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	• 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	• 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				
Final Exam	Written or oral exam (120 min)				
Language	English				
Work load (hours)	Contact time	Self-studies	Total		
	45 h	105	150		

3.3.17. Fundamentals of Semiconductors & Optoelectronics (5 ECTS)

Lecture 07LE33V-HL	**Fundamentals of Semiconductors & Optoelectronics**				**5 ECTS**
Lecturer/s	apl. Prof. Dr. Joachim Wagner (Fraunhofer IAF)				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L+E)	2 + 1	5	SL or PL	WiSe
Frequency	The lecture is offered regularly in the winter semester.				
Qualification objectives	• 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 semi-conductors 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	• 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	• 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				
Final Exam	Oral exam (30 min)				
Language	English or German				
Work load (hours)	Contact time	Self-studies	Total		
	45 h	105	150		

3.3.18. Mechanical Properties and Degradation Mechanisms (3 ECTS)

Lecture 11LE50V-5115	**Mechanical Properties and Degradation Mechanisms** **3 ECTS**				
Lecturer/s	Prof. Dr. Chris Eberl (Fraunhofer IWM)				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L)	2	3	SL	SoSe
Frequency	Only in the summer semester				
Qualification objectives	The goal is to learn how materials properties and their impact on functionality and performance of micro systems. You will learn about the physical mechanisms in structural and functional materials as well as damage evolution during the applications lifetime. Based on the physical understanding you can evaluate microsystem designs, improve their lifetime and performance. This allows specifying materials and systems closer to their performance limit.				

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

Literature	• M. Ohring: „The Materials Science of Thin Films“, Academic Press, 1992 • L.B. Freund and S. Suresh: „Thin Film Materials“ • T.H. Courtney: „Mechanical Behaviour of Materials“, Mc-Graw-Hill, 1990 • M. Madou: “Fundamentals of Microfabrication“, CRC Press 1997 • W. Menz und P. Bley: „Mikrosystemtechnik für Ingenieure“, VCH Publishers, 1993 • Chang Liu: Foundations of MEMS, Illinois ECE Series, 2006				
Preliminaries	-				
Final Exam	written or oral examination				
Language	English				

Work load (hours)	Contact time	Self-studies	Total
	30	60	90

3.3.19. Theory and Modeling of Materials (5 ECTS)

<table>
<tr><th>Lecture
07LE33V-MODMAT</th><th colspan="5">Theory and Modeling of Materials 5 ECTS</th></tr>
<tr><td>Lecturer/s</td><td colspan="5">apl. Prof. Dr. Christian Elsässer (Fraunhofer IWM)</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Examina-tion</td><td>term</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>2 + 1</td><td>5</td><td>SL</td><td>SoSe and WiSe</td></tr>
<tr><td>Frequency</td><td colspan="5">Courses of the lecture series are offered regularly in alternating order.</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">• 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</td></tr>
<tr><td>Course content</td><td colspan="5">The series of one- or two-semester elective-subject lectures introduces theoretical models and computational methods of solid-state physics for the description of many-electron systems, by means of which cohesion and structure, physical, chemical, or mechanical properties of perfect crystals and real materials can be understood qualitatively and calculated quantitatively on a microscopic fundament.
The lecture series comprises courses on, e.g., these topics:
• Electronic-structure theory of condensed matter I + II
• Superconductivity I (phenomenology) + II (microscopic theory)
• Theoretical models for magnetic properties of materials
• Theory of atomistic and electronic structures at interfaces in crystals
• etc.
The content of each course will be announced for each semester.</td></tr>
<tr><td>Literature</td><td colspan="5">recommended literature will be announced in each lecture</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="5">Theoretical physics and solid-state physics on the level of a BSc in Physics</td></tr>
<tr><td>Final Exam</td><td colspan="5">Oral exam (30 min)</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td rowspan="2">Work load (hours)</td><td colspan="2">Contact time</td><td colspan="2">Self-studies</td><td>Total</td></tr>
<tr><td colspan="2">45 h</td><td colspan="2">105</td><td>150</td></tr>
</table>

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

<table>
<tr><th>Lecture
07LE33V-DFT</th><th colspan="5">Computational Physics: Density Functional Theory 7 ECTS</th></tr>
<tr><td>Lecturer/s</td><td colspan="5">Prof. Dr. Michael Moseler</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Examina-tion</td><td>term</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>3 + 2</td><td>7</td><td>SL or PL</td><td>WiSe or SoSe</td></tr>
<tr><td>Frequency</td><td colspan="5">The lecture is offered irregularly.</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">• Students are familiar with electronic structure calculations.
• Students are familiar with the basic Hamiltonian of the electronic structure problem and electronic many-body wave function.
• Students know the Hartree-Fock equations and post Hartree-Fock methods – such as Møller-Plesset and Configurational Interaction.
• Students are familiar with the Hohenberg-Kohn-theorem, the Kohn-Sham-equations, the concept of an exchange-correlation potential and the various local approximations to it.
• Student arefamiliar with time-dependent DFT and know the Runge-Gross-theorem and the time-dependent Kohn-Sham-equations.</td></tr>
<tr><td>Course content</td><td colspan="5">Density functional theory (DFT) has become one of the most important tools for the numerical solution of the electronic many-body Schrödinger equation. It is currently used by many material scientists to study the properties complex systems containing up to several thousand atoms and electrons. This lecture introduces the theoretical foundations of DFT within the Hohenberg-Kohn-Sham frame work. It also touches numerical questions in an accompanying hands-on course. Numerical exercises will cover the electronic structure of atoms and nanoparticles.</td></tr>
<tr><td>Literature</td><td colspan="5">• Lecture script: Electronic structure of matter</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="5">Basic knowledge in many-body quantum mechanics</td></tr>
<tr><td>Final Exam</td><td colspan="5">Written or oral exam (60 min)</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td rowspan="2">Work load (hours)</td><td colspan="2">Contact time</td><td colspan="2">Self-studies</td><td>Total</td></tr>
<tr><td colspan="2">75 h</td><td colspan="2">135</td><td>210</td></tr>
</table>

3.3.21. Quantum Transport (7 ECTS)

<table>
<tr><td>Lecture
07LE33V-QTRANS</td><td colspan="5">Quantum Transport 7 ECTS</td></tr>
<tr><td>Lecturer/s</td><td colspan="5">PD Dr. Michael Walter, PD Dr. Thomas Wellens</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Examina-tion</td><td>term</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>3 + 2</td><td>7</td><td>SL or PL</td><td>SoSe</td></tr>
<tr><td>Frequency</td><td colspan="5">The lecture is offered regularly in the summer semester.</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">• Students become familiar with advanced theoretical tools relevant for quantum transport theory (Green functions, scattering theory, diagrammatic methods for performing disorder average, Landau-Büttiker formalism)
• Students understand how quantum effects modify the transport behaviour in various physical systems</td></tr>
<tr><td>Course content</td><td colspan="5">How to describe transport of a particle from one point in space to another one is a fundamental problem in theoretical physics, which is at the same time highly relevant for many technological applications, for example in electronics (transport of electrons) or solar cells (separation of positive and negative charge carriers generated by light). On microscopic scales, quantum properties -- such as the wave nature of a quantum particle, or the quantization of energy levels -- become relevant and make quantum transport different from classical transport based on Newton's equations. In this lecture, we will approach the topic of quantum transport from different perspectives, with focus on (i) transport of quantum particles (or waves) in disordered structures which are described in a statistical way, and (ii) the explicit description of transport in an electronic device at the atomic scale, with the single molecule transistor as prominent example, which is likely to be the basis of future electronics.</td></tr>
<tr><td>Literature</td><td colspan="5">• 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 University Press, Cambridge, England, 2005).</td></tr>
<tr><td>Preliminaries / Previous knowledge</td><td colspan="5">Basic quantum mechanics</td></tr>
<tr><td>Final Exam</td><td colspan="5">Written (90 min) or oral (60 min) exam</td></tr>
</table>

Language	English or German		
Work load (hours)	Contact time	Self-studies	Total
	75 h	135	210

3.3.22. Modelling and System Identification (6 ECTS)

Lecture 11LE50MO-2080	**Modelling and System Identification**				**6 ECTS**
Lecturer/s	Prof. Dr. Moritz Diehl (IMTEK)				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L+E)	2 + 2	6	SL or PL	WiSe
Frequency	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	• Lecture manuscript • Ljung, L. (1999). System Identification: Theory for the User. Prentice Hall • Lecture manuscript "System Identification" by J				
Preliminaries / Previous knowledge	Differential Equations, Systems Theory and Feedback Control				
Final Exam	Written or oral exam				
Language	English				
Work load (hours)	Contact time	Self-studies	Total		
	64 h	116	180		

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

<table>
<tr><th>Lecture
09LE03V-SP2-04_0003</th><th colspan="5">Computational Neuroscience:
Models of Neurons and Networks 7 ECTS</th></tr>
<tr><td>Lecturer/s</td><td colspan="5">Prof. Dr. Stefan Rotter (Faculty of Biology, Bernstein Center Freiburg)</td></tr>
<tr><td rowspan="2">Course details</td><td>Type</td><td>Credit hrs</td><td>ECTS</td><td>Examina-tion</td><td>term</td></tr>
<tr><td>Lecture and exercises (L+E)</td><td>2 + 2</td><td>7</td><td>SL</td><td>SoSe</td></tr>
<tr><td>Frequency</td><td colspan="5">The lecture is offered regularly in the summer semester.</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">The students have the competence to
link mathematical models with biological phenomena arising in systems neuroscience both using theory and computer simulations;
understand the fundamental trade-off between biological detail and mathematical abstraction, and evaluate its consequences;
explain the steps necessary to develop and validate models of a biological neuron or a biological neuronal network;
appreciate and explain the gain in understanding biological mechanisms that arise from the study of mathematical models of neuronal systems;
critically discuss the limits of mathematical modeling and numerical methods in computational neuroscience.</td></tr>
<tr><td>Course content</td><td colspan="5">This lecture series covers important standard topics in computational neuroscience, focusing on dynamic networks of spiking neurons
Mathematical concepts and methods
Hodgkin-Huxley theory of the action potential
Stochastic theory of ionic channels
The integrate-and-fire neuron model
Stochastic point processes
Stochastic theory of synaptic integration
Stochastic theory of spike generation: The perfect integrator
Stochastic theory of spike generation: The leaky integrator
Conductance based neurons and networks
Correlated neuronal populations
Pulse packets and synfire chains
Random graphs and networks
Dynamics of spiking networks
Population dynamics of recurrent networks.</td></tr>
<tr><td>Literature</td><td colspan="5">lecture slides
a bibliography and web-links to complementary reading for each course day will be provided along with the slides of the lecture.</td></tr>
</table>

Preliminaries / Previous knowledge	Familiarity with elementary calculus and linear algebra is assumed. Background in basic neurobiology is helpful, but not required.		
Final Exam	Written exam (120 min), oral exam (60 min) or term paper (10 pages), in combination with course below.		
Language	English		
Work load (hours)	Contact time	Self-studies	Total
	105 h	105 h	210 h

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

Lecture 09LE03Ü-SP2-04_0004	**Computational Neuroscience:** **Simulation of Biological Neuronal Networks** **5 ECTS**				
Lecturer/s	Prof. Dr. Stefan Rotter (Faculty of Biology, Bernstein Center Freiburg), Prof. Dr. Abigail Morrison (FZ Jülich)				
Course details	**Type**	**Credit hrs**	**ECTS**	**Examina-tion**	**term**
	Lecture and exercises (L+E)	1 + 2	5	SL	SoSe
Frequency	The course is offered regularly as a 2-week block in the summer semester.				
Qualification objectives	The students have the competence to • 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 on a computer; • critically discuss the limits of mathematical modeling and numerical methods in computational neuroscience.				
Course content	This course covers the fundamentals of simulating networks of single-compartment spiking neuron models. We start from the concept of a point neuron and then introduce more complex topics such as phenomenological models of synaptic plasticity, connectivity patterns and network dynamics.				
Literature	• lecture slides • see also http://www.nest-initiative.org/ for some general information and an online tutorial on the BNN simulator NEST				
Preliminaries / Previous knowledge	Basic knowledge in scientific computing with Python is absolutely required. Self-study is possible, see http://www.python.org/ for some general information and an online tutorial on the programming language Python. Further documentation on the scientific libraries used in the course is also found online (see http://scipy.org/).				
Final Exam	Written exam (120 min), oral exam (60 min) or term paper (10 pages), in combination with course above.				

Language	English		
Work load (hours)	Contact time	Self-studies	Total
	60 h	90 h	150 h

3.3.25. Solar Physics (5 ECTS)

Lecture 07LE33V-SOLPHYS	**Solar Physics**			**5 ECTS**
Lecturer/s	Prof. Dr. Oskar von der Lühe (Kiepenheuer-Inst. for Solar Physics, KIS)			
Course details	**Type**	**Credit hrs**	**ECTS**	**Examination**
	Lecture and exercises (L+E)	2 + 1	5	SL or PL
Frequency	The lecture is offered every second winter semester.			
Qualification objectives	• Students obtain advanced knowledge about the Sun as a template star and as a complex physical system. Students also obtain knowledge about modern tools to research the Sun and their physical basis. • Students understand the role of the Sun as the central component of the Solar system, its interaction with the heliosphere, and its impact on the near-Earth environment, the Earth's climate and on modern civilization.			
Course content	• The Sun in the astrophysical context • Internal structure of the Sun • Solar rotation, convection and magnetism • The solar atmosphere • Chromosphere, corona and the solar wind • Sun – Earth interaction and space weather • The Why's and How's of solar observations			
Literature	• M. Stix, The Sun – An Introduction (2^{nd} Ed.), Springer • P. Foukal, Solar Astrophysics (3^{rd} Ed.), Wiley • Lecture Script (through ILIAS)			
Preliminaries / Previous knowledge	Experimental Physics I – IV. Completion of an introductory course on astro-physics (e. g. bachelor course) is highly recommended.			
Final Exam	Regular participation in exercises (SL) Written (120 min) or oral (30 min) exam (PL)			
Language	English			
Work load (hours)	Contact time	Self-studies	Total	
	45 h	105	150	

3.3.26. Modern Astronomical Instrumentation (5 ECTS)

Lecture 07LE33V-ASTRINST	**Modern Astronomical Instrumentation**			**5 ECTS**
Lecturer/s	Prof. Dr. Oskar von der Lühe (Kiepenheuer-Inst. for Solar Physics, KIS)			
Course details	**Type**	**Credit hrs**	**ECTS**	**Examination**
	Lecture and exercises (L+E)	2 + 1	5	SL or PL
Frequency	The lecture is offered every second winter semester.			
Qualification objectives	• Students obtain an overview of observing facilities and instruments in which are used for astronomy to observe the e. m. spectrum, astroparticles and gravitational waves • Students understand the design principles of optical instruments in general and obtain an introduction to modern lens design			
Course content	• Introduction to geometrical optics and aberration theory • Design and construction of astronomical telescopes for the whole spectrum of e. m. waves on the ground and in space • Post-focus instrumentation for astronomical telescopes • Spectroscopy and polarimetry • Detectors for astronomy • Radio telescopes • Detection of astroparticles and gravitational waves.			
Literature	• P. Léna, Observational Astrophysics, Springer • Landolt - Börnstein Group VI Vol. 4 Astronomy, Springer • Lecture Script (through ILIAS)			
Preliminaries / Previous knowledge	Experimental Physics I – IV. Completion of an introductory course on astrophysics (e. g. bachelor course) is highly recommended.			
Final Exam	Regular participation in exercises (SL) Written (120 min) or oral (30 min) exam (PL)			
Language	English			
Work load (hours)	Contact time	Self-studies	Total	
	45 h	105	150	

3.3.27. Lab Course in Astrophysics (5 ECTS)

Course 07LE33P-ASTROLAB	**Lab course in Astrophysics** **(Astronomisches Praktikum)** **5 ECTS**			
Lecturer/s	apl Prof. Dr. Wolfgang Schmidt (Kiepenheuer-Inst. for Solar Physics, KIS)			
Course details	**Type**	**Credit hrs**	**ECTS**	**Examination**
	Lab	4	5	SL and PL
Frequency	The course is offered regularly in the summer semester.			
Qualification objectives	• Students gain hands-on experience with a solar and a stellar telescope. • Students obtain some familiarity with modern data analysis tools • Students learn how important properties of the Sun are derived from spectroscopic observations • Students have the opportunity to directly observe remote objects in the milky Way (e.g., Star Clusters) and learn how to measure the age of such clusters.			
Course content	The lab course in astrophysics takes place each year in the summer semester at the observatory of the KIS on Schauinsland. Several experiments with astrophysical background are carried out (a) with the 45 cm solar tower telescope, and (b) with the 35 cm (stellar) Maksutov telescope: • Operate the solar telescope and the Littrow spectrograph • Measuring solar rotation (a) via Doppler effect and (b) by tracking sunspots • Measuring magnetic field in sunspots • Age estimation of star clusters (color photometry)			
Literature	• Description of the experiments (download from KIS web page) • Weigert, Wendker, Wisotzki: Astronomie & Astrophysik (5. Auflage), ISBN: 978-3-527-67095-6			
Preliminaries / Previous knowledge	• Introductory course in astrophysics (Bachelor course) • Familiarity with computers & basic knowledge in programming			
Final Exam	Participation in whole course (SL) Written report on one experiment and data analysis (PL)			
Language	English			
Work load (hours)	Contact time	Self-studies	Total	
	45 h	105	150	

3.4. Elective Subjects (10 ECTS credit points)

<table>
<tr><td>Module:
07LE33K-
ELSUB_APHYS</td><td colspan="6">Elective Subjects 10 ECTS</td></tr>
<tr><td>Responsibility</td><td colspan="6">Dean of Studies,
or Faculty/Institute responsible for selected course</td></tr>
<tr><td rowspan="3">Courses</td><td></td><td>Type</td><td>Credit hrs</td><td>CP</td><td>Exami-nation</td><td>Term</td></tr>
<tr><td>courses in the M.Sc. Applied Physics and/or other M.Sc./M.A. pro-grams by own choice</td><td>L+E</td><td>According to selected courses</td><td>10</td><td>SL</td><td>WiSe+SoSe</td></tr>
<tr><td>Total:</td><td></td><td></td><td>10</td><td></td><td></td></tr>
<tr><td>Organization</td><td colspan="6">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.</td></tr>
<tr><td>Module mark</td><td colspan="6">-</td></tr>
<tr><td>Qualification objectives</td><td colspan="6">The qualification objects are subject to the selected course.</td></tr>
<tr><td>Course content</td><td colspan="6">The course content is subject to the selected course.</td></tr>
<tr><td rowspan="3">Work load (hours)</td><td colspan="2">Course</td><td colspan="2">Contact time</td><td>Self-studies</td><td>Total</td></tr>
<tr><td colspan="2">Elective courses</td><td colspan="3">subject to selected courses</td><td>300 h</td></tr>
<tr><td colspan="2">Total:</td><td colspan="3"></td><td>300 h</td></tr>
<tr><td>Usability</td><td colspan="6">M.Sc. Applied Physics</td></tr>
<tr><td>Previous knowledge</td><td colspan="6">Subject to selected courses</td></tr>
<tr><td>Language</td><td colspan="6">Subject to selected courses</td></tr>
</table>

3.5. Term Paper (6 ECTS credit points)

Module: 07LE33M-TP	**Term Paper**					**6 ECTS**
Responsibility	Dean of Studies, Lecturers of the Institute of Physics or associated institutes					
Courses		**Type**	**Credit hrs**	**CP**	**Exami-nation**	**Term**
	Term paper seminar	S	2	6	PL	WiSe+SoSe
	Total:			**6**		
Organization	The research groups 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.					
Module mark	A mark is given for the oral presentation on a current research topic and the written documentation (hand-out).					
Qualification objectives	• Students are able to handle scientific literature and search in 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 presentation and are able to incorporate didactical elements					
Course content	The *Term Paper* seminar comprises approximately 10 lectures from a coherent field of physics or a neighboring scientific area and consists of the elaboration of a lecture to a physics topic or an adjacent area with written documentation (hand-out) and an oral presentation. Beyond that, active participation in all lectures of the seminar is expected.					

Work load (hours)	**Course**	**Contact time**	**Self-studies**	**Total**
	Term paper seminar	30 h	150 h	180 h
	Total:	**30 h**	**150 h**	**180 h**
Usability	M.Sc. Applied Physics, M.Sc. Physics			
Previous knowledge	Basic knowledge in respective topic acquired e.g. in a corresponding lecture			
Language	English			

3.6. Master Laboratory Applied Physics (8 ECTS credit points)

Module: 07LE33M-MLAB_APHYS	**Master Laboratory Applied Physics**					**8 ECTS**
Responsibility	Dean of studies, Head of the master laboratory					
Courses	**Course**	**Type**	**Credit hrs**	**CP**	**Examina-tion**	**Term**
	Master Laboratory	Lab	10	8	PL	WiSe
	Total:			**8**		
Organization	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). For each experiment, students prepare a written report, which is part of the final assessment.					
Module grade	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 to the final module grade (weighted mean).					
Qualification objectives	• Students are able to perform 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 experimental results					
Course content	The current catalogue of laboratory experiments is available online on http://www.physik.uni-freiburg.de/studium/labore					
Work load (hours)	**Course**	**Contact time**	**Self-studies**	**Total**		
	Master Laboratory	120 h (16 days * 7.5h)	120 h	240 h		
	Total:	**120 h**	**120 h**	**240 h**		
Usability	M.Sc. Applied Physics					
Previous knowledge	- Experimental skills as acquired e.g. in the Physics Laboratory during B.Sc. - Statistical methods of data analysis					
Language	English					

List of laboratory experiments (to be completed):

The students may select laboratory experiments from the following list according to their interest and availability. Ideally, the intended field of specialization should guide the choice of experiments.

3.6.1. Experiment: MR Imaging: Contrasts and Methods

Experiment 1	**MR Imaging: Contrasts and Methods**
Responsible group/person	Prof. Dr. Michael Bock (Universitäts Klinikum)
Short description	In this practical course the students will be introduced to the usage of a clinical high field MRI system. A phantom will be constructed, and the relaxation time T1 of different solutions will be measured. In a volunteer experiment, MR image contrasts and imaging methods will be demonstrated and assessed systematically.
Duration (in days)	2 day(s) = 1 ECTS point
Recommended preliminary knowledge	• Principles of MRI • Lecture on Physics of Medical Imaging
Safety requirements	Experiments will be performed at a clinical MRI system at field strengths of 1.5 T or 3 T – to be able to work at the MR magnet students must fulfil all safety requirements for MRI (e.g., no pacemaker). A safety introduction will be provided.

3.6.2. Experiment: Infrared Spectroscopy for Analytical Applications

Experiment 2	**Infrared Spectroscopy for Analytical Applications**
Responsible group/person	Dr. Frank Kühnemann (IPM)
Short description	In this experiment, the students will be introduced to the use of infrared spectroscopic techniques for analytical applications. Examples are absorption measurements of atmospheric gases and the characterization of liquids and solids.
Duration (in days)	2 day(s) = 1 ECTS point

Recommended preliminary knowledge	Advanced Optics and Lasers, Advanced Atomic and Molecular Physics
Safety requirements	laser safety instructions (provided by IPM)

3.6.3. Experiment: Light Scattering of Colloidal Crystals

Experiment 3	**Light Scattering of Colloidal Crystals**
Responsible group/person	Prof. Dr. Günter Reiter
Short description	The scattering of light by polycrystalline samples of spherical colloids is studied using the Debye-Scherrer technique. Several lasers with different wavelengths are employed to increase the number of detectable reflections.
Duration (in days)	2 day(s) = 1 ECTS point
Recommended preliminary knowledge	Lattice structures, Bragg scattering
Safety requirements	laser safety instructions

3.7. Research Traineeship (30 ECTS credit points)

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**		**CP**	**Examination**
	Research (under supervision)	6 months	30	SL
Organization	Prior to their Master thesis students engage in a Research Traineeship which is accomplished in a six-month period. The aim of this module is to acquire basic knowledge in a certain research topic and field in preparation for the subsequent Master Thesis. For the traineeship, students select a supervisor at the Institute of Physics or at one of the associated and participating research institutes. The research traineeship can be started any time and has a duration of exactly 6 months. The students have to register for the research traineeship at the examination office.			
Qualification objectives	• Students have a 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 specialized field of research. • Students are prepared for performing a self-dependent research project (preparation for Master Thesis)			
Course content	• Students acquire basic knowledge in a certain field of research in preparation for their Master Thesis. • Participants obtain training in applying experimental and/or theoretical tools in a specialized field of research. • Students participate in a current research project under the supervision of lecturers and researchers (post-docs and doctoral researchers).			
Work load (hours)	900 h distributed over a six-month period			
Usability	M.Sc. Applied Physics, M.Sc. Physics			
Precondition	Admission to the Research Traineeship requires successful accomplishment of the module *Master Laboratory Applied Physics* and of three of the four marked courses (PL) of the modules *Advanced Experimental Physics*, *Advanced Theoretical Physics, Applied Physics* and *Term Paper*.			
Language	English			

3.8. Master Thesis (30 ECTS points)

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

Precondition	Admission to the Master Thesis requires successful accomplishment of the module *Research Traineeship*.
Language	English or German (in case of German the written thesis has to comprise an abstract in English)