Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Fachbereich Physik

Module catalogue

Physik (M.Sc.) and Physics (M.Sc.)

Universität Hamburg

English translation 25.01.23

The following detailed module descriptions are structured as follows:

<table>
<tr><th>Module title</th><th colspan="5"></th></tr>
<tr><td>Module number</td><td colspan="5">PHY-MV-…</td></tr>
<tr><td>Semester</td><td colspan="5">Wintersemester/Summersemester</td></tr>
<tr><td>Applicability, module type and assignment to the curriculum</td><td colspan="5">• …
• …</td></tr>
<tr><td>Prerequisites for participation</td><td colspan="5">Binding:
Recommended:</td></tr>
<tr><td>Responsible person</td><td colspan="5"></td></tr>
<tr><td>Lecturers</td><td colspan="5"></td></tr>
<tr><td>Language</td><td colspan="5">Which language of instruction? German or English?</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">What learning outcomes should students have achieved after successfully have achieved after successful completion of the module?
z. e.g. in the sense of:
- Learning outcomes that demonstrate knowledge or application: e.g. define/ represent/ measure/ report/ evaluate information, theory and/or factual knowledge.
- Learning outcomes that demonstrate the practical skills using knowledge: e.g. perform, demonstrate, etc.</td></tr>
<tr><td>Content</td><td colspan="5">The (teaching) content should state the aims of the module. (Which subject-specific, methodical, practical and interdisciplinary contents should be taught in order to achieve the module objectives?)</td></tr>
<tr><td>Courses and teaching forms
V= Vorlesung (lecture)
Ü= Übung (exercises)
S= Seminar (seminar)
P= Praktikum (laboratory, practical)</td><td colspan="4">How many SWS (hrs per semester week) for V and/or Ü and/or S and/or P?
• (V)
• (Ü)
• …</td><td>SWS
SWS</td></tr>
<tr><td rowspan="2">Workload*
(partial performances and total)
*LP = Credit point
*P = Attendance study
*S = Self-study
*PV = Exam preparation</td><td></td><td>LP</td><td>P (hrs)</td><td>S (hrs)</td><td>PV (hrs)</td></tr>
<tr><td>Total workload</td><td></td><td></td><td></td><td></td></tr>
</table>

Study / Examination achievements	Type of examination: Written or oral examinationination or presentation and/or written paper, project completion, internship completion, ... Language of the examination
Duration	1 or 2 semester
Frequency of the course	Every semester, annually or every 4 semesters?
Literaturee	

Pflichtmodule *(Compulsory modules)*:

<table>
<tr><th>Module title</th><th colspan="5">Introductory Project / Einarbeitungsprojekt</th></tr>
<tr><td>Module number</td><td colspan="5">PHY-MF-A/BE/BP/FN/LP-EP</td></tr>
<tr><td>Semester</td><td colspan="5">Wintersemester and Summersemester</td></tr>
<tr><td>Applicability, module type and assignment to the curriculum</td><td colspan="5">• Physik (M.Sc.): Pflichtmodul
• Physics (M.Sc.): Pflichtmodul</td></tr>
<tr><td>Prerequisites for participation</td><td colspan="5">Binding: s. FSBs zu § 4
Recommended:</td></tr>
<tr><td>Responsible person</td><td colspan="5">Members of the group of university professors of the Department of Physics</td></tr>
<tr><td>Lecturers</td><td colspan="5">Members of the teaching staff from the Department of Physics</td></tr>
<tr><td>Language</td><td colspan="5">German or English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">In the familiarisation project, the study of a modern research field, from which the topic of the Master's thesis is to originate, has been deepened with the aim of familiarising oneself with the scientific Literaturee at the current level.
The student learns how to independently collect the necessary information, background knowledge and familiarisation with a special topic.
For this module, the student is integrated into a scientific working group. Through the involvement in a working group, he or she learns group work and the optimal use of informal knowledge in a close-knit environment.</td></tr>
<tr><td>Content</td><td colspan="5">- Familiarisation with the subject area;
- Familiarisation with theoretical and/or experimental working techniques and tools;
- Working on partial aspects;
- Formulation of a work plan and time schedule.</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Independent scientific work under guidance</td><td>15 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>• Independent scientific work under guidance</td><td>LP
15</td><td>P (hrs)
-</td><td>S (hrs)
390</td><td>PV (hrs)
60</td></tr>
<tr><td>Total workload</td><td>15</td><td>-</td><td>390</td><td>60</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: project completion
Language of the exam:
Physik (M.Sc.): German or English
Physics (M.Sc.): English</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">every semester</td></tr>
<tr><td>Literature</td><td colspan="5">To be announced in the course.</td></tr>
</table>

Module title	**Preparatory Project / Vorbereitungsprojekt**	
Module number	PHY-MF-A/BE/BP/FN/LP-VP	
Semester	Wintersemester and Summersemester	
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Pflichtmodul • Physics (M.Sc.): Pflichtmodul	
Prerequisites for participation	Binding: Successful completion of the module Introductory Project Recommended:	
Responsible person	Members of the group of university professors of the Department of Physics	
Lecturers	Members of the teaching staff from the Department of Physics	
Language	German or English	
Qualification objectives	By working on preparatory tasks, the student has acquired the specific experimental and/or theoretical methods and knowledge of the field to such an extent that he or she can successfully apply them to work on questions from which the topic of the Master's thesis is to originate. Planning and structuring of the intended research project. The associated working group seminar serves to familiarise the student with problems of current research in the subject in which the candidate intends to conduct the Master's thesis. For this module, the student is integrated into a scientific working group. Through the involvement in a working group, he or she learns group work and the optimal use of informal knowledge in a close-knit environment.	
Content	Einführung in das wissenschaftliche Arbeiten und die fachlichen und methodischen Grundlagen für die Masterarbeit sowie Planung des in der Masterarbeit zu bearbeitenden Forschungsprojekts. Introduction to scientific work and the subject-specific and methodological basics for the Master's thesis as well as planning of the research project to be worked on in the Master's thesis. Acquisition of the necessary experimental and theoretical-mathematical skills, which are a prerequisite for the successful completion of the research task of the subsequent Master's thesis. In the working group seminar, various topics of the working group's field of work are presented and discussed. A presentation (preferably in English) is compulsory for all students. The module forms an inseparable unit with the preceding module "familiarisation project" and the subsequent module "master's thesis" and must therefore be taken in the same research area in which the master's thesis is to be written.	
Courses and teaching forms	• Independent scientific work under guidance	15 SWS

Workload (partial performances and total)	• Independent scientific work under guidance	LP 15	P (hrs) -	S (hrs) 390	PV (hrs) 60
	Total workload	15	-	390	60
Study / Examination achievements	Studienleistung: project completion Type of examination: Lecture/Colloquium Language of the exam: Physik (M.Sc.): German or English Physics (M.Sc.): English				
Duration	1 semester				
Frequency of the course	every semester				
Literature	To be announced in the course.				

Module title	**Master's Thesis / Masterarbeit**	
Module number	PHY-MF-MA	
Semester	Wintersemester and Summersemester	
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Pflichtmodul • Physics (M.Sc.): Pflichtmodul	
Prerequisites for participation	Binding: Successful completion of the moduleVorbereitungsprojekt Recommended:	
Modulverantwortliche®	Members of the group of university professors of the Department of Physics	
Lecturers	Members of the teaching staff from the Department of Physics	
Language	German or English	
Qualification objectives	The Master's thesis should show that the candidate is able to familiarise himself/herself with a problem of current research in the subject within the given time limit, to apply suitable scientific methods increasingly independently and to present the results in a scientifically appropriate form.	
Content	The master's thesis forms the conclusion of the master's programme. The Master's thesis consists of - the implementation of a research or scientific development project; - experimental and/or theoretical treatment of the topic; - the evaluation and processing of the results; - the written documentation of the results by writing the Master's thesis; - an oral presentation of the results in a lecture and scientific discussion. The results should contribute to a scientific publication.	
Courses and teaching forms	• Independent scientific work in a team	30 SWS

Workload (partial performances and total)	• Independent scientific work in a team	LP 30	P (hrs) -	S (hrs) 830	PV (hrs) 70
	Total workload	30	-	830	70
Study / Examination achievements	Type of examination: Master‘s thesis (1/6), colloquium (1/6) Language of the exam: Physik (M.Sc.): German or English Physics (M.Sc.): English				
Duration	1 semester				
Frequency of the course	every semester				
Literature	To be announced in the course.				

Wahlmodule (Complementary subject)**:**

Module title:	**Wahlbereich**				
Module number:	**WAHL (je nach anbietendem Fach)**				
Semester	Summersemester, Wintersemester				
Applicability, module type and assignment to the curriculum	Physik (B.Sc.); Physik (M.Sc.); Physics (M.Sc.): Elective module				
Prerequisites for participation:	According to the offering subject.				
Responsible person:	Members of the teaching staff from the offering subject				
Lecturers:	Members of the teaching staff from the offering subject				
Language:	According to the offering subject.				
Qualification objectives	Students have basic knowledge of either astrophysics and astronomy, biomedical physics or a subject area outside physics.				
Content:	There are no restrictions on the choice of subject area; students should follow their inclinations and interests. Only the time required for the elective area (12 credit points) is fixed. The number of credit points can be achieved by combining different modules, which must be meaningfully related.				
Courses and teaching forms:	• According to the offering department (V, Ü, S, P)				
Workload	• According to the offering department (V, Ü, S, P)	LP	P (hrs) …	S (hrs) …	PV (hrs) …

(partial performances and total)		12			
	Total workload	12	...	...	...
Study / Examination achievements	• According to the offering department.				
Duration	1 semester				
Frequency of the course	According to the offering department				
Literature:	To be announced in the courses.				

Fachliche Vertiefungsphase (Advanced Master's Courses):

Astronomie und Astrophysik (Astronomy and Astrophysics):

Module title	**Laborastrophysik**				
Module number	PHY-MV-A-E02				
Semester	Wintersemester and Summersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: none				
Responsible person	Prof. Dr. Günter Wiedemann				
Lecturers	Prof. Dr. Günter Wiedemann				
Language	German or English				
Qualification objectives	The students know laboratory physics as the foundation of observational astrophysics. Thus, they have the ability to define necessary laboratory experiments by implementing the requirements of observational astronomy as well as planning and carrying out astrophysically relevant measurements in the HS laboratory and to obtain and evaluate astrophysically relevant measurement data under realistic conditions.				
Content	Introduction to laboratory operation & equipment; methods of laboratory astrophysics; definition and planning of a measurement experiment; preparation and execution, evaluation and interpretation.				
Courses and teaching forms	• Laborastrophysik (V) • Übungen zur Laborastrophysik (Ü)				2 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	3 2	28 28	32 32	30 -
	Total workload	5	56	64	30
Study / Examination achievements	Type of examination: Colloquium Language of the exam: German or English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	every semester				
Literature	To be announced in the course.				

Module title	**Astronomische Beobachtungsmethoden und -instrumente**
Module number	PHY-MV-A-E12
Semester	Wintersemester and Summersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Günter Wiedemann
Lecturers	Prof. Dr. Günter Wiedemann
Language	German or English
Qualification objectives	The students know the most important astronomical observation methods and instruments, modern IR/optical technologies and the interactions between astronomical research and both technical and experimental basics.
Content	Basics of observational astronomy; methods (photometry, spectroscopy, astrometry etc); instruments (telescopes, measuring instruments, detectors); applications in observational astrophysics; practical exercises. The practical part can be carried out at the observatory (Bergedorf).
Courses and teaching forms	• Astronomische Beobachtungsmethoden und -instrumente (V) — 2 SWS • Übungen zu Astronomische Beobachtungsmethoden und -instrumente (Ü) — 2 SWS
Workload (partial performances and total)	see table below
Study / Examination achievements	Type of examination: oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	every semester
Literature	To be announced in the course.

Workload	LP	P (hrs)	S (hrs)	PV (hrs)
• Lecture	3	28	32	30
• Exercises	2	28	32	-
Total workload	5	56	64	30

Module title	**Cosmology**
Module number	PHY-MV-A-E14

Semester	Wintersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: Einführung in die Astronomie I und II				
Responsible person	Prof. Dr. Markus Brüggen				
Lecturers	Prof. Dr. Markus Brüggen				
Language	English				
Qualification objectives	The students know problem-solving strategies. They are able to think analytically and theorise in physics and are able to apply mathematical and information-technological solution strategies.				
Content	Basic knowledge of cosmology in theory and observation.				
Courses and teaching forms	• Cosmology (V) • Exercises in Cosmology (Ü)				3 SWS 1 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	5 1	42 14	54 16	54 -
	Total workload	6	56	70	54
Study / Examination achievements	Type of examination: Written or oral examination *written or oral examinationination* Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	Annually, Wintersemester				
Literature	To be announced in the course.				

Module title	**Seminar Topics in Low Frequency Radio Astronomy**
Module number	PHY-MV-A-E15
Semester	Wintersemester/Summersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Einführung in die Astronomie I und II
Responsible person	Prof. Dr. Markus Brüggen

Lecturers	Prof. Dr. Markus Brüggen				
Language	English				
Qualification objectives	Students know the basics of scientific discourse and current research in low-frequency radio astronomy.				
Content	Current research in low-frequency radio astronomy				
Courses and teaching forms	• Seminar Topics in Low Frequency Radio Astronomy (S)				2 SWS
Workload (partial performances and total)	• Seminar	LP 3	P (hrs) 28	S (hrs) 32	PV (hrs) 30
	Total workload	3	28	32	30
Study / Examination achievements	Type of examination: Referat mit schriftlicher Ausarbeitung Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	To be announced in the course.				

Module title	**Extragalactic Astrophysics**
Module number	PHY-MV-A-E17
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Einführung in die Astronomie I und II
Responsible person	Prof. Dr. Markus Brüggen
Lecturers	Prof. Dr. Markus Brüggen
Language	English
Qualification objectives	The students know problem-solving strategies and are able to think analytically. They have the ability to evaluate astronomical data and to develop theories in physics. The students are able to apply mathematical and information-technical solution strategies.
Content	Basic knowledge of extragalactic astronomy in theory and observation; Milky Way system, large-scale structure, galaxy formation, galaxy clusters.

Courses and teaching forms	• Extragalactic Astrophysics (V) • Exercises in Extragalactic Astrophysics (Ü)				3 SWS 1 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	5 1	42 14	54 16	54 -
	Total workload	6	56	70	54
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	To be announced in the course.				

Module title	**Seminar Extragalactic Astrophysics**				
Module number	PHY-MV-A-E19				
Semester	Wintersemester and Summersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: Einführung in die Astronomie I und II				
Responsible person	Prof. Dr. Markus Brüggen				
Lecturers	Prof. Dr. Markus Brüggen				
Language	English				
Qualification objectives	Students are able to present research results, read and understand technical Literature and evaluate astronomical data. They also have the knowledge of theory building in physics.				
Content	Modern topics from current research in extragalactic astronomy.				
Courses and teaching forms	• Seminar Extragalactic Astrophysics (S)				2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Seminar	3	28	32	30
	Total workload	3	28	32	30
Study / Examination achievements	Type of examination: Referat mit schriftlicher Ausarbeitung Language of the exam: English				

	Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	every semester
Literature	To be announced in the course.

Module title	**Galaxy Evolution**				
Module number	PHY-MV-A-E23				
Semester	Summersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: Einführung in die Astronomie & Astrophysik I & II				
Responsible person	Prof. Dr. Jochen Liske				
Lecturers	Prof. Dr. Jochen Liske				
Language	English				
Qualification objectives	Students are familiar with the evolution of the universe, the linear and non-linear growth of cosmic structures, the formation of elliptical and spiral galaxies, and the observational techniques used to observe galaxies.				
Content	Overview of galaxies and physical processes, cosmological background, (statistical) properties of galaxies, growth of density perturbations, formation of Dark Matter halos, formation of gaseous halos, linking halos to galaxies, formation of disks, observational facilities.				
Courses and teaching forms	• Galaxy Evolution (V) • Exercises in Galaxy Evolution (Ü)				2 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	3 2	28 28	32 32	30 -
	Total workload	5	56	64	30
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	biennial				

Literature	"Galaxy Formation and Evolution", Mo, van den Bosch and White, Cambridge University Press.

<table>
<tr><th>Module title</th><th colspan="5">Seminar on Galaxy Evolution</th></tr>
<tr><td>Module number:</td><td colspan="5">PHY-MV-A-E24</td></tr>
<tr><td>Semester</td><td colspan="5">Summersemester</td></tr>
<tr><td>Applicability, module type and assignment to the curriculum</td><td colspan="5">• Physik (M.Sc.): Compulsory elective module
• Physics (M.Sc.): Compulsory elective module</td></tr>
<tr><td>Prerequisites for participation</td><td colspan="5">Binding: none
Recommended: Einführung in die Astronomie & Astrophysik I & II</td></tr>
<tr><td>Responsible person</td><td colspan="5">Prof. Dr. Jochen Liske</td></tr>
<tr><td>Lecturers</td><td colspan="5">Prof. Dr. Jochen Liske</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">The students are able to read scientific publications and critically reflect on them. The students are able to reproduce the contents of publications and to describe their context in a presentation.</td></tr>
<tr><td>Content</td><td colspan="5">This seminar covers some of the classic scientific papers on galaxy formation and evolution, both theoretical and observational.</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Seminar on Galaxy Evolution (S)</td><td>2 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>• Seminar</td><td>LP
3</td><td>P (hrs)
28</td><td>S (hrs)
32</td><td>PV (hrs)
30</td></tr>
<tr><td>Total workload</td><td>3</td><td>28</td><td>32</td><td>30</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Referat mit schriftlicher Ausarbeitung
Language of the exam: English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">annually</td></tr>
<tr><td>Literature</td><td colspan="5">To be announced in the course.</td></tr>
</table>

Module title	**Chemical Evolution of the Universe**
Module number	PHY-MV-A-E27
Semester	Summersemester

<table>
<tr><td>Applicability, module type and assignment to the curriculum</td><td colspan="5">• Physik (M.Sc.): Compulsory elective module
• Physics (M.Sc.): Compulsory elective module</td></tr>
<tr><td>Prerequisites for participation</td><td colspan="5">Binding: none
Recommended: Einführung in die Astronomie I und II</td></tr>
<tr><td>Responsible person</td><td colspan="5">Prof. Dr. Jochen Liske</td></tr>
<tr><td>Lecturers</td><td colspan="5">Prof. Dr. Jochen Liske</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">Students are familiar with the most important astrophysical processes relevant for the chemical evolution of the Universe.</td></tr>
<tr><td>Content</td><td colspan="5">Cosmological background, primordial nucleosynthesis, structure formation, basics of stellar evolution and nucleosynthesis, neutron capture processes, galactic chemical evolution, cosmic chemical evolution.</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Chemical Evolution of the Universe (V)
• Exercises in Chemical Evolution of the Universe (Ü)</td><td>2 SWS
2 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>
• Lecture
• Exercises</td><td>LP
3
2</td><td>P (hrs)
28
28</td><td>S (hrs)
32
32</td><td>PV (hrs)
30
-</td></tr>
<tr><td>Total workload</td><td>5</td><td>56</td><td>64</td><td>30</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Written or oral examination
Language of the exam: English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">biennial</td></tr>
<tr><td>Literature</td><td colspan="5">„Nucleosynthesis and Chemical Evolution of Galaxies”, Pagel, Cam-bridge University Press</td></tr>
</table>

Module title:	**Computational Astrophysics**
Module number:	PHY-MV-A-T01
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation:	Binding: none Recommended: Einführung in die Astronomie I und II, elementare Programmierkenntnisse

Responsible person:	Prof. Dr. Peter Hauschildt				
Lecturers:	Prof. Dr. Peter Hauschildt				
Language:	English (Folien/Skript auf English)				
Qualification objectives	The students are able to use numerical methods in a targeted manner and to critically evaluate the results of computer programs.				
Content:	Topics covered include hardware basics, parallelisation, GPUs, common pitfalls, non-linear equations, linear equations, differential equations, Monte Carlo methods, and FFT/wavelets.				
Courses and teaching forms:	• Computational Astrophysics (V) • Exercises in Computational Astrophysics (ü)				3 SWS 1 SWS
Arbeitsaufwand* (Teilleistungen und insgesamt)		LP	P(hrs)	S (hrs)	PV (hrs)
	• Lecture	5	42	54	54
	• Exercises	1	14	16	-
	Total workload	6	56	70	54
Study / Examination achievements	Type of examination: Written exam Deviations will be announced at the beginning of the events.				
Duration	1 semester				
Frequency of the course	biennial				
Literature:	Skript; Press et al, 'Numerical Receipes in [Fortran, C]'				

Module title	**Stellar Structure & Evolution**
Module number	PHY-MV-A-T02
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Peter Hauschildt
Lecturers	Prof. Dr. Peter Hauschildt
Language	English

Qualification objectives	The students know the physical structure of stars and their evolution.				
Content	This is a lecture in theoretical astrophysics. It describes the physics underlying stellar structure and evolution. The physical processes in the interior of the star and properties of the stellar matter are discussed. Furthermore, the calculation of stellar models and typical results are discussed. The development from the pre-main sequence to the final stages of stars of different masses is discussed. The properties and evolution of normal and compact stars are described.				
Courses and teaching forms	• Stellar Structure & Evolution (V) • Exercises in Stellar Structure & Evolution (Ü)				3 SWS 1 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	5 1	70 14	40 16	40 -
	Total workload	6	84	56	40
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	biennial				
Literature	Kippenhahn, Weigert, Weiss: Stellar Structure and Evolution http://emedien.sub.uni-hamburg.de/han/SpringerEbooks/dx.doi.org/10.1007/978-3-642-30304-3				

Module title	**Theory and Application of PHOENIX**
Module number	PHY-MV-A-T03
Semester	Wintersemester/Summersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: very good programming skills in Fortran90 and MPI, proven basic knowledge of PHOENIX Recommended: Einführung in die Astronomie I+II, Computational Astrophysics, Stellar and planetary atmospheres
Responsible person	Prof. Dr. Peter Hauschildt
Lecturers	Prof. Dr. Peter Hauschildt
Language	English

Qualification objectives	The students have a better understanding of PHOENIX, including the methods, algorithms and programme modules used. They know the application of PHOENIX to astrophysical simulation problems.				
Content	The different modules of PHOENIX are discussed and reviewed. Practical experiences in the application of PHOENIX will be discussed.				
Courses and teaching forms	• Theory and Application of PHOENIX (V)				2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	3	28	32	30
	Total workload	3	28	32	30
Study / Examination achievements	Prerequisites for registering for the module examination: active participation Type of examination: Oral examination Language of the exam: English Deviations will be announced at the beginning of the events.				
Duration	1 semester				
Frequency of the course	Every semester				
Literature	To be announced in the course.				

Module title	**Stellar and Planetary Atmospheres**				
Module number	PHY-MV-A-T04				
Semester	Wintersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: Einführung in die Astrophysik I & II				
Responsible person	Prof. Dr. Peter Hauschildt				
Lecturers	Prof. Dr. Peter Hauschildt				
Language	English				
Qualification objectives	Students will understand the structure of stellar and planetary atmospheres, radiative transfer and numerical models of atmospheres, as well as the formation of spectra and their critical interpretation.				
Content	The structure of stellar and planetary atmospheres, radiative transfer and numerical models of atmospheres, and the formation of species.				
Courses and teaching forms	• Stellar and Planetary Atmospheres (V) • Exercises in Stellar and Planetary Atmospheres (Ü)				3 SWS 1 SWS
Workload		LP	P (hrs)	S (hrs)	PV (hrs)

(partial performances and total)	• Lecture • Exercises	5 1	42 14	54 16	54 -
	Total workload	6	56	70	54
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	biennial				
Literature	To be announced in the course.				

Module title	**MHD simulations with the FLASH code**				
Module number	PHY-MV-A-T06				
Semester	Wintersemester/Summersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module Empfehlung 2. oder 3. FS • Physics(M.Sc.): Compulsory elective module Empfehlung 2. oder 3. FS				
Prerequisites for participation	Binding: none Recommended: Knowledge of numerical methods and magnetohydrodynamics				
Responsible person	Prof. Dr. Robi Banerjee				
Lecturers	Prof. Dr. Robi Banerjee				
Language	English				
Qualification objectives	Students know how to use the simulation code FLASH and applications in the astrophysical field.				
Content	Selected topics in magnetohydrodynamics (MHD) and numerical solutions of MHD problems.				
Courses and teaching forms	• MHD simulations with the FLASH code (V)				2 SWS
Workload (partial performances and total)	• Seminar	LP 3	P (hrs) 28	S (hrs) 32	PV (hrs) 30
	Total workload	3	28	32	30
Study / Examination achievements	Requirements for registration for the module examination: successful participation in the exercises Type of examination: Oral examination Language of the exam: English Deviations will be announced at the beginning of the events.				

Duration	1 semester
Frequency of the course	Every semester
Literature	To be announced in the course.

Module title	**The Interstellar Medium and Star Formation**
Module number	PHY-MV-A-T10
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Einführung in die Astrophysik I & II
Responsible person	Prof. Dr. Robi Banerjee
Lecturers	Prof. Dr. Robi Banerjee
Language	German or English
Qualification objectives	The students have basic knowledge of the interstellar medium (including composition, physical properties, dynamics) and the formation of stars (including prerequisites, time scales, thermodynamics, development of protostars, gas outflows). Furthermore, they know the hydrodynamic and magneto-hydrodynamic equations and can apply them.
Content	ISM (three phases + physical properties); Molecular clouds (observations + physical properties); Conditions for star formation (i.e. cold dense regions, Jeans criterion, BE spheres) Turbulence (Larson's relation, Kolmogorov turbulence); Fragmentation; Initial mass function (IMF, reconstruction from observations); IMF (theoretical ideas, conversion from CMF to IMF); The collapse (1D calculations: Larson/Penston, Shu); Magnetic fields: mass-to-flux ratio, ambipolar diffusion; Magnetic fields: observational techniques (polarisation, Zeeman, RM); 3D collapse: disc formation, Jets; Jet launching; Observations of Jets; Formation of Massive stars; Feedback (HII-Regions, SN) + triggered star formation; Protostellar evolution (Hayashi track, classes); Evolution of protoplanetary discs; Planet formation (grav. instability, core accretion models).

Courses and teaching forms	• Interstellar Medium and Star Formation (V) • Exercises in Interstellar Medium and Star Formation (Ü)				3 SWS 1 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	5	42	54	54
	• Exercises	1	14	16	-
	Total workload	6	56	70	54
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	biennial				
Literature	Frank Shu "The Physical Universe"; Bruce Drain "Physics of the Interstellar and Intergalactic Medium"; Steven Stahler & Francesco Palla "The Formation of Stars"; Derek Ward-Thomson & Anthony Whitworth "An Introduction to Star Formation".				

Module title	Introduction to General Relativity and Astrophysical Applications
Module number	PHY-MV-A-T16
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Einführung in die Astrophysik I & II
Responsible person	Prof. Dr. Robi Banerjee
Lecturers	Prof. Dr. Robi Banerjee
Language	English
Qualification objectives	The students know the general theory of reality. They have knowledge about curved spaces in more dimensions and can describe them. They also know astrophysical phenomena based on ART.
Content	curvilinear space; concepts of Special Relativity and SPACETIME; Equivalence Principle; curved SPACETIME; Geodesics; Tensor calculus; Einsteins' field equation. Applications: Schwarzschild geometry, Black Holes (BH), Kerr BHs, Accretion Discs, Gravitational lensing, Gravitational Waves, Gravitational Wave Sources, Cosmology

Courses and teaching forms	• Introduction to General Relativity and Astrophysical Applications (V) • Exercises in Introduction to General Relativity and Astrophysical Applications (Ü)				4 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	6 2	56 28	62 32	62 -
	Total workload	8	84	94	62
Study / Examination achievements	Type of examination: Written exam Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	biennial				
Literature	James B. Hartle: GRAVITY, An Introduction to Einstein's General Relativity; Ray d'Inverno: Introducing Einstein's Relativity; Bernhard Schutz: A First Course in General Relativity.				

Beschleuniger- und Elementarteilchenphysik (Accelerator and elementary particle physics):

Module title	**Accelerator Physics II**
Module number	PHY-MV-BE-E02
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Besuch der Lecture „Accelerator Physics I“
Responsible person	Prof. Dr. Wolfgang Hillert
Lecturers	Prof. Dr. Wolfgang Hillert
Language	English
Qualification objectives	The students understand the most important interrelationships in the planning and further development of accelerator facilities. They have deeper insights into the design and application of modern accelerators such as synchrotron radiation sources, high-energy colliders or free electron lasers. They know the most important effects limiting the beam quality and intensity as well as the achievable luminosity and methods to generate high-intensity and coherent X-rays.
Content	This course is a continuation and consolidation of the introductory course "Accelerator Physics I". In principle, it is possible to start directly with the

	advanced course without having attended the introductory course. However this requires an independent familiarization with the matrix formalism describing the linear beam optics which in general should be easily possible due to existing very good textbooks. Contents: - Synchrotron radiation and radiation equilibrium - Synchrotron radiation sources - Space charge effects (direct space charge) - Luminosity and colliders - Phase space cooling (stochastic cooling, electron cooling) - Free electron lasers
Courses and teaching forms	• Accelerator Physics II (V) — 2 SWS • Exercises in Accelerator Physics II (Ü) — 2 SWS
Workload (partial performances and total)	see workload table below
Study / Examination achievements	Type of examination: Successful work with the exercises, final oral examination Language of the exam: English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	annually
Literature	• H. Wiedemann, Particle Accelerator Physics (Third Edition), Springer 2007, Berlin, ISBN 978-3-5-540-490343-2 • D. A. Edwards, M. J. Syphers, An Introduction to the Physics of High Energy Accelerators, Wiley & Sons 1993, New York, ISBN 0-471-55163-5 • F. Hinterberger, Physik der Teilchenbeschleuniger und Ionenoptik (2. Ausgabe), Springer 2008, Berlin, ISBN 978-3-540-75282-0 • K. Wille, Physik der Teilchenbeschleuniger und Synchrotronstrahlungsquellen, 2. überarb. und erw. Aufl., Teubner 1996, Stuttgart, ISBN 3-519-13087-4 (vergriffen) • K. Wille, The physics of particle accelerators, Oxford Univ. Press 2005, Oxford, ISBN 0-19-850550-7 • S. Y. Lee, Accelerator Physics (Third Edition), World Scientific 2012, New Jersey, ISBN 978-981-4374-94-1 • A. W. Chao, K. H. Mess, M. Tigner, F. Zimmermann, Handbook of Accelerator Physics and Engineering (Second Edition), World Scientific 2013, New Jersey, ISBN 978-981-4415-84-2 • Script of the lecture "Accelerator Physics I"

Workload (partial performances and total):

	LP	P (hrs)	S (hrs)	PV (hrs)
• Lecture	3	28	32	30
• Exercises	2	28	32	-
Total workload	5	56	64	30

<table>
<tr><th>Module title</th><th colspan="5">Experimental Astroparticle Physics</th></tr>
<tr><td>Module number</td><td colspan="5">PHY-MV-BE-E05</td></tr>
<tr><td>Semester</td><td colspan="5">Wintersemester</td></tr>
<tr><td>Applicability, module type and assignment to the curriculum</td><td colspan="5">• Physik (M.Sc.): Compulsory elective module
• Physics (M.Sc.): Compulsory elective module</td></tr>
<tr><td>Prerequisites for participation</td><td colspan="5">Binding: none
Recommended: Astrophysik</td></tr>
<tr><td>Responsible person</td><td colspan="5">Prof. Dr. Dieter Horns; Prof. Dr. Caren Hagner</td></tr>
<tr><td>Lecturers</td><td colspan="5">Prof. Dr. Dieter Horns; Prof. Dr. Caren Hagner</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">The students are able to put concrete experiments and their measurements into a context and are able to critically question which interpretation of the measurement results is appropriate. They can understand how a measurement or observation concept is derived from a physical question in the field of astroparticle physics. The students learn to work out current research results in joint discourse within the framework of seminar presentations.</td></tr>
<tr><td>Content</td><td colspan="5">Astroparticle physics with a focus on neutrino physics (neutrino detection, neutrino generation, neutrino oscillation), cosmic accelerators (generation, propagation and detection of cosmic radiation). In addition, current topics from the relevant areas of astroparticle physics (dark matter, cosmology, etc.).</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Experimental Astroparticle Physics (V)
• Exercises in Experimental Astroparticle Physics (Ü)</td><td>4 SWS
2 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>
• Lecture
• Exercises</td><td>LP
6
2</td><td>P (hrs)
56
28</td><td>S (hrs)
62
32</td><td>PV (hrs)
62
-</td></tr>
<tr><td>Total workload</td><td>8</td><td>84</td><td>94</td><td>62</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Studienleistung: Vortrag
Type of examination: Oral examination
Language of the exam: English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">annually</td></tr>
<tr><td>Literature</td><td colspan="5">To be announced in the course.</td></tr>
</table>

Module title	**Accelerator Physics I**

<table>
<tr><th>Module number</th><th colspan="5">PHY-MV-BE-E09</th></tr>
<tr><td>Semester</td><td colspan="5">Wintersemester</td></tr>
<tr><td>Applicability, module type and assignment to the curriculum</td><td colspan="5">Nanowissenschaften (M.Sc.): Compulsory elective module
Physik (M.Sc.): Compulsory elective module
Physics (M.Sc.): Compulsory elective module</td></tr>
<tr><td>Prerequisites for participation</td><td colspan="5">Binding: none
Recommended: none</td></tr>
<tr><td>Responsible person</td><td colspan="5">Prof. Dr. Wolfgang Hillert</td></tr>
<tr><td>Lecturers</td><td colspan="5">Prof. Dr. Wolfgang Hillert</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">Students know the basics of accelerator physics and are able to design the basic elements of a simple accelerator facility themselves and calculate its key parameters.
In detail:
- Understanding of the functional principle of different types of particle accelerators.
- Conception and design of simple magneto-optical systems
- Basic knowledge of radio frequency engineering and technology at particle accelerators
- Knowledge of linear beam dynamics in particle accelerators and their application</td></tr>
<tr><td>Content</td><td colspan="5">- Overview of accelerator types: electrostatic accelerators and induction accelerators, DTL, RFQ, Alvarez, linac, cyclotron, synchrotron, microtron.
- Components of accelerators: Particle sources, radio frequency systems and cavities, magnets, vacuum systems
- Linear beam optics: equations of motion, matrix formalism, beam parameters, phase space representation
- Circular accelerators: periodic magnetic structures, transverse and longitudinal beam dynamics
- Visits to accelerators on the DESY site (e.g. FLASH, PETRA III, HERA) to illustrate and deepen the subject matter.</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">Accelerator Physics I (V)
Exercises in Accelerator Physics I (Ü)</td><td>2 SWS
2 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>Lecture
Exercises</td><td>LP
3
2</td><td>P (hrs)
28
28</td><td>S (hrs)
32
32</td><td>PV (hrs)
30
-</td></tr>
<tr><td>Total workload</td><td>5</td><td>56</td><td>64</td><td>30</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Successful work with the exercises, final oral examinationination
Language of the exam: English
Deviations will be announced at the beginning of the event.</td></tr>
</table>

Duration	1 semester
Frequency of the course	annually
Literature	• S. Y. Lee: *Accelerator Physics*, 3rd edition, World Scientific, New Jersey 2011, ISBN 978-981-4374-94-1 • K. Wille: *Physik der Teilchenbeschleuniger und Synchrotron-strahlungsquellen,* 2. überarb. und erw. Auflage, Teubner 1996, Stuttgart, ISBN 978-3-519-13087-1 • K. Wille: *The physics of particle accelerators,* Oxford Univ. Press 2005, Oxford, ISBN 0-19-850550-7 (engl. Übersetzung, teuer!) • D. A. Edwards, M. J. Syphers: *An Introduction to the Physics of High Energy Accelerators,* Wiley & Sons 1993, New York, ISBN 0-471-55163-5 • F. Hinterberger: *Physik der Teilchenbeschleuniger und Ionenoptik,* 2. Ausgabe, Springer 2008, Berlin, ISBN 978-3-540-75281-3 • H. Wiedemann: *Particle Accelerator Physics I,* 4th edition, Springer 2015, Berlin, ISBN 978-3-319-18316-9 • A. W. Chao, M. Tigner: *Handbook of Accelerator Physics and Engineering,* 2nd edition, World Scientific, Singapore, 2013, ISBN 978-4417-17-4

Module title	**Physik und Anwendungen von Laser-Plasma-Beschleunigern: Von medizinischer Bildgebung bis Hochenergiephysik**
Module number	PHY-MV-BE-E15
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Florian Grüner
Lecturers	Prof. Dr. Florian Grüner
Language	German or English
Qualification objectives	After successful completion of the module, the students know the basics of the so-called plasma wakefield acceleration, and know where the ultra-high field gradients come from and why the electro-nuclear bunches are so short. Their knowledge can be applied in the following areas: - Synchrotron and undulator radiation - Free-electron lasers (FELs) - table-top FELs driven by laser plasma accelerators

	- medical imaging with laser-based undulator sources
Content	In addition to modern and well-established accelerators, a new field is emerging in accelerator physics: laser plasma accelerators. They are based on so-called high-power lasers that can accelerate electrons in plasmas of a few centimetres in length to GeV energies. This compactness promises new applications, from medical imaging to brilliant X-ray sources to high-energy physics. We discuss in detail the underlying physics with a focus on the brilliant X-ray sources, in particular the linking of laser plasma accelerators and free-electron lasers.

Courses and teaching forms	• Physik und Anwendungen von Laser-Plasma-Beschleunigern: Von medizinischer Bildgebung bis Hochenergiephysik (V) • Übungen zur Physik und Anwendungen von Laser-Plasma-Beschleunigern: Von medizinischer Bildgebung bis Hochenergiephysik (Ü)	4 SWS 2 SWS

		LP	P (hrs)	S (hrs)	PV (hrs)
Workload (partial performances and total)	• Lecture • Exercises	6 2	56 28	62 32	62 -
	Total workload	8	84	94	62

Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	annually
Literature	To be announced in the lecture

Module title	**Teilchenphysik und der Large Hadron Collider (LHC): Beschleuniger, Detektoren und Physik**
Module number	PHY-MV-BE-E18
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Teilchenphysik für Fortgeschrittene
Responsible person	Prof. Dr. Johannes Haller
Lecturers	Prof. Dr. Johannes Haller
Language	German or English

Qualification objectives	The students have an in-depth understanding of the current topics in particle physics, in particular of the research topics that are being investigated at the LHC.				
Content	Introduction, accelerator and the LHC, basics of pp collisions, track detectors at the LHC, QCD and electroweak processes at the LHC, calorimeters of the LHC detectors, trigger and data acquisition systems, physics of the top quark, search and study of the Higgs boson, search for new physics, search for supersymmetry, outlook.				
Courses and teaching forms	• Teilchenphysik und der Large Hadron Collider (LHC): Beschleuniger, Detektoren und Physik (V) • Übungen zur Teilchenphysik und der Large Hadron Collider (LHC): Beschleuniger, Detektoren und Physik (Ü)				4 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	6	56	62	62
	• Exercises	2	28	32	-
	Total workload	8	84	94	62
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	„Elementarteilchenphysik“, Berger, Springer, 2006 „Collider Physics“, Barger + Phillips, Addison Wesley „Quarks and Leptons“, Halzen + Martin, Wiley, 1984 „Feynman-Graphen und Eichtheorien für Experimentalphysiker“, Schmüser, Springer, 1988 „Physics at the Terascale“, Brock+ Schörner-Sadenius (Eds.) Wiley, 2011 The ATLAS Experiment at the CERN LHC, JINST 3:S08003, 2008 The CMS Experiment at the CERN LHC, JINST 3:S08004, 2008				

Module title	**Quantenmechanik II**
Module number	PHY-MV-BE-T01
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Lecture Theoretische Physik II (Quantenmechanik I)

Responsible person	Prof. Dr. Peter Schmelcher				
Lecturers	Members of the teaching staff from the Department of Physics				
Language	German or English				
Qualification objectives	The students know systematic treatment of the quantum mechanical description of many-particle systems and relativistic quantum mechanics as well as the concept of field operators in second quantisation. They have the ability to mathematically describe relativistic particles (fermions and bosons).				
Content	Second quantisation; multi-particle states; Fock space; field operators; fermions and bosons; scattering theory and correlation functions; relativistic wave equations: Klein-Gordon and Dirac equation; covariance and symmetries of the Dirac equation; Dirac equation in the electromagnetic field: exact solutions and radiation corrections.				
Courses and teaching forms	• Quantenmechanik II (V) • Übungen zur Quantenmechanik II (Ü)				4 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	6 2	56 28	62 32	62 -
	Total workload	8	84	94	62
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	notes of the lecturer; C. Cohen-Tannoudji, B. Diu, and F. Laloe, Quantum Mechanics, Volume 2; John Wiley & Sons, 1991; F. Schwabl, Quantenmechanik für Fortgeschrittene (QM II), Springer, 2008; S. Weinberg, Quantum Mechanics, Cambridge University Press, 2013.				

Module title	**Physics of the Standard Model**
Module number	PHY-MV-BE-T02
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none

	Recommended: Quantenmechanik, Kern- und Teilchenphysik, Quantum Field Theory I, Advanced Particle Physics
Responsible person	Prof. Dr. Gudrid Moortgat-Pick
Lecturers	Members of the teaching staff from the Department of Physics
Language	English
Qualification objectives	The students know the structure of the Standard Model (QCD and electroweak sector), have applied quantum field theory, group theory and gauge symmetries, learn the perturbation theory approaches, know the basics of pp- and ei-based accelerator ex-periments (LHC, lepton accelerator) and can perform studies in both theo-retical and experimental physics.
Content	Yang-Mills theories, QCD phenomenology, renormalisation, linking couplings, electroweak interactions, Higgs mechanism, collider phenomenology, Monte Carlo simulation, Fourier physics, CKM matrix, CP violation, neutrino physics and oscillations, anomalies, BL, strong CP, drawbacks of the Standard Model.

Courses and teaching forms		
	• Physics of the Standard Model (V)	3 SWS
	• Exercises in Physics of the Standard Model (Ü)	1 SWS

Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	5	42	54	54
	• Exercises	1	14	16	-
	Total workload	6	56	70	54

Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	annually
Literature	Quantum Field theory and the Standard Model, Matthew Schwartz The Standard Model, a primer, Burgess and Moore A modern introduction to QFT, Maggiore An introduction to QFT, Peskin and Schroeder

Module title	**Introduction to Supersymmetry and Supergravity**
Module number	PHY-MV-BE-T03
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Theoretische Physik I und II

<table>
<tr><td>Responsible person</td><td colspan="5">Prof. Dr. Gudrid Moortgat-Pick</td></tr>
<tr><td>Lecturers</td><td colspan="5">Members of the teaching staff from the Department of Physics</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">The students know the mathematical structure of supersymmetry, learn to apply the supersymmetric Lie algebra, calculate in superspace and can perform supersymmetric transformations and field theoretical calculations in supergravity and know the GUT theory.</td></tr>
<tr><td>Content</td><td colspan="5">- Introduction to the principles of supersymmetry and supergravity
- Supersymmetry algebra and its representation theory
- Supersymmetric Yang-Mills Theories
- The supersymmetric standard model
- Extended supersymmetry and Seiberg-Witten theory
- Supergravity and its coupling to matter.
- Extended supergravities and their geometric properties
- Supersymmetry and supergravity in arbitrary dimensions</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Introduction to Supersymmetry and Supergravity (V)
• Exercises in Introduction to Supersymmetry and Supergravity (Ü)</td><td>3 SWS
1 SWS</td></tr>
<tr><td rowspan="3">Workload
(partial performances and total)</td><td></td><td>LP</td><td>P (hrs)</td><td>S (hrs)</td><td>PV (hrs)</td></tr>
<tr><td>• Lecture
• Exercises</td><td>5
1</td><td>42
14</td><td>54
16</td><td>54
-</td></tr>
<tr><td>Total workload</td><td>6</td><td>56</td><td>70</td><td>54</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Written or oral examination
Language of the exam: English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">annually</td></tr>
<tr><td>Literature</td><td colspan="5">Weinberg, S, Quantum Field Theory 3, Supersymmetry</td></tr>
</table>

Module title	**Quantenfeldtheorie I**
Module number	PHY-MV-BE-T04
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Theoretische Physik I und II

<table>
<tr><td>Responsible person</td><td colspan="5">Prof. Dr. Gleb Arutyunov</td></tr>
<tr><td>Lecturers</td><td colspan="5">Members of the teaching staff from the Department of Physics</td></tr>
<tr><td>Language</td><td colspan="5">German or English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">The aim of the course is to provide both a theoretical and technical introduction to quantum field theory.
Students know canonical quantisation and path integral quantisation techniques for bosonic and fermionic fields with emphasis on symmetries, functional techniques with the generating functional and correlation functions and perturbation theories in the form of Feynman diagrams. They know the formulation of non-Abelian gauge theories.
Upon completion of the module, students have the knowledge of Poincaré and internal symmetries, Noether's theorem, discrete symmetries, canonical quantisation of Klein-Gordon, Dirac and electromagnetic fields, the concept of gauge invariance, asymptotic states and S-matrix, the path integral quantisation, the definition of correlation functions, the generating functional of correlation functions, the Wick theorem, Feynman diagrams, self-energy and vertex functions, and dimensional regularisation and renormalisation group.
For a given Lagrangian density, students are able to identify its global and local symmetries to determine the dynamical invariants, derive the Feynman rules and construct the Feynman diagrams for a given scattering process or correlation function.</td></tr>
<tr><td>Content</td><td colspan="5">Canonical quantisation and path integral quantisation techniques for bosonic and fermionic fields will be discussed in depth. Emphasis will be placed on symmetries, functional techniques with the generating functional and correlation functions, and perturbation theory in the form of Feynman diagrams. A bird's eye view on renormalisation techniques and non-Abelian gauge theories will be offered. The lecture will be complemented with exercises.</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Quantenfeldtheorie I (V)
• Übungen zur Quantenfeldtheorie I (Ü)</td><td>4 SWS
2 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>• Lecture
• Exercises</td><td>LP
6
2</td><td>P (hrs)
56
28</td><td>S (hrs)
62
32</td><td>PV (hrs)
62
-</td></tr>
<tr><td>Total workload</td><td>8</td><td>84</td><td>94</td><td>62</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Written or oral examination
Language of the exam: German or English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">annually</td></tr>
<tr><td>Literature</td><td colspan="5">notes of the lecturer;
T. Lancaster and S. J. Blundell, Quantum Field Theory for the Gifted Amateur, Oxford University Press, 2014;</td></tr>
</table>

	M. E. Peskin and D. V. Schroeder, An Introduction to Quantum Field Theory, Perseus Books, The Advanced Book Program, 1995.

Module title	**Quantenfeldtheorie II**
Module number	PHY-MV-BE-T06
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Theoretische Physik I und II, Quantenfeldtheorie I
Responsible person	Prof. Dr. Gleb Arutyunov
Lecturers	Members of the teaching staff from the Department of Physics
Language	German or English
Qualification objectives	The students have a deepened and extended knowledge of quantum field theory. They know renormalisation techniques, non-Abelian gauge theories and their covariant quantisation methods. They can discuss spontaneous symmetry breaking and topological solutions in quantum field theory. The learning outcome further includes the understanding of the basics of the S-matrix of quantum electrodynamics, including the self-energy of the electron, vacuum polarisation and the anomalous magnetic moment of the electron. Furthermore, it includes the knowledge of the covariant Faddeev-Popov method and the BRST symmetry. The Goldstone theorem and the Higgs phenomenon are also part of the curriculum. Students will be able to derive renormalisation group equations for the vertex and Green's functions to calculate the beta function in quantum electrodynamics to a loop and in a generic non-Abelian gauge theory. You will gain an understanding of the Landau pole and asymptotic freedom and be able to explain the consequences of spontaneous breaking of global and local symmetries.
Content	The aim of the course is to deepen and broaden the knowledge of quantum field theory and to further develop the students' competence. This includes a through treatment of renormalisation techniques, introduction to non-Abelian gauge theories and their covariant quantisation methods, discussion of spontaneous symmetry breaking and topological solutions in quantum field theory. The lecture is complemented by exercises.

Courses and teaching forms		
	• Quantenfeldtheorie II (V)	4 SWS
	• Übungen zur Quantenfeldtheorie II (Ü)	2 SWS

Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	6	56	62	62
	• Exercises	2	28	32	-

	Total workload	8	84	94	62
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	Lecturesskript / Notes of the lecturer; M. E. Peskin and D. V. Schroeder, An Introduction to Quantum Field Theory, Perseus Books, The Advanced Book Program, 1995.				

Module title	**Theory of General Relativity**				
Module number	PHY-MV-BE-T07				
Semester	Wintersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: klassische Feldtheorie, Quantenmechanik, Kern- und Teilchenphysik				
Responsible person	Prof. Dr. Günter Sigl				
Lecturers	Members of the teaching staff from the Department of Physics				
Language	English				
Qualification objectives	The students know the basics of general relativity. They are able to tackle research projects on topics of field theory, theoretical cosmology and mathematical physics, for example within the framework of a Master's thesis.				
Content	Principles of relativity, special relativity, basics of differential geometry, Einstein equations, Schwarzschild metrics, experimental tests of gravitational theory, gravitational waves, basics of and applications to cosmology.				
Courses and teaching forms	• Thoery of General Relativity (V) • Exercises in Thoery of General Relativity (Ü)				4 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	6	56	62	62
	• Exercises	2	28	32	-
	Total workload	8	84	94	62

Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	annually
Literature	Steven Weinberg: Gravitation and Cosmology, New York: John Wiley and Sons, 1972. Steven Weinberg (2008), Cosmology, Oxford University Press Robert M. Wald: General Relativity, University of Chicago Press, 1984. C. W. Misner, K. S. Thorne, J. A. Wheeler: Gravitation, Palgrave Macmil-lan, 1973. Sean M. Carroll: Spacetime and Geometry: An Introduction to General Relativity, Addison Wesley, 2009. Sean M. Carroll: Lecture Notes on General Relativity. L. D. Landau, E. M. Lifshitz: Lehrbuch der theoretischen Physik II: Klassische Feldtheorie, Akademie Verlag Berlin 1984. Bernard F. Schutz: A First Course in General Relativity, Cambridge University Press, New York 1985 (2nd edition 2009). Bernard F. Schutz: Gravity from the Ground Up, Cambridge University Press, New York 2003. E. F. Taylor, J. A. Wheeler: Exploring Black Holes: Introduction to Gen-eral Relativity, Addison-Wesley Longman, San Francisco 2000. J. B. Hartle: Gravity: An Introduction to Einstein's General Relativity, Addison-Wesley, San Francisco 2003.

Module title	**Introduction to String Theory**
Module number	PHY-MV-BE-T11
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Stringsteilkurs
Responsible person	Prof. Dr. Volker Schomerus
Lecturers	Members of the teaching staff from the Department of Physics
Language	English
Qualification objectives	After successful attendance of the lecture, students will be able to read further Literaturee and recent research papers in the field of string theory.

Content	This course covers the basics of string and superstring theory in flat and curved backgrounds. Topics include: Classical strings, quantization, relation with gauge theory and gravity, supersymmetry, superstring theories as well as selected chapters of 2-dimensional conformal quantum field theory, Calabi-Yau compactifications and the AdS/CFT correspondence.				
Courses and teaching forms	• Introduction to String Theory (V) • Exercises in Introduction to String Theory (Ü)				2 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	3	28	32	30
	• Exercises	2	28	32	-
	Total workload	5	56	64	30
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	To be announced in the course.				

Module title	**Phenomenology of Physics beyond the Standard Model**
Module number	PHY-MV-BE-T12
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Quantenmechanik, Kern- und Teilchenphysik, Quantum Field Theory I, Advanced particle Physics or Physics of the Standard Model
Responsible person	Prof. Dr. Gudrid Moortgat-Pick
Lecturers	Members of the teaching staff from the Department of Physics
Language	English
Qualification objectives	The students know the open questions of the standard model (dark matter, baryon-antibaryon asymmetry, etc.).), which extensions of the theory are possible to clarify these questions, which description possibilities there are (effective theories, concrete models), get an overview of models and learn about their symmetries and structure and with which observables these models can be delegated to accelerator-based (LHC, e+e accelerator, Muon accelerator) and non-accelerator-based experiments (gravitational waves, ALPS, etc.).

Content	Phenomenology at accelerators for different models of physics beyond the Standard Model, supersymmetry, extra dimension model-le, models with extra gauge bosons, Yang-Mills theories, QCD phenomenology, renormalisation, linking couplings, Electroweak interactions, Higgs mechanism, Higgs physics, LHC phenomenology, Monte Carlo tools, flavour physics, CKM matrix, CP violation, neutrino physics and oscillations, anomalies, B-L, strong CP, drawbacks of the Standard Model.				
Courses and teaching forms	• Phenomenology of Physics beyond the Standard Model (V) • Exercises in Phenomenology of Physics beyond the Standard Model (Ü)				3 SWS 1 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	5 1	42 14	54 16	54 -
	Total workload	6	56	70	54
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	Quantum Field theory and the Standard Model, Matthew Schwartz The Standard Model, a primer, Burgess and Moore A modern introduction to QFT, Maggiore An introduction to QFT, Peskin and Schroeder				

Module title	**Quantum Chromodynamics (Advanced Topic in Particle Physics)**
Module number	PHY-MV-BE-T22
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Grundkenntnisse der Teilchenphysik, Kenntnisse in Quantenfeldtheorie
Responsible person	Prof. Dr. Gudrid Moortgat-Pick
Lecturers	Prof. Dr. Gudrid Moortgat-Pick, Dr. Markus Diehl
Language	English
Qualification objectives	The participants know the main features of quantum chromodynamics as a quantum field theory, in particular the role played by symmetries and

	quantum loops. Furthermore, the participants will be able to evaluate the challenges of a quantitative description of the processes at modern particle colliders, in particular the LHC.				
Content	- Symmetries of QCD and their consequences - Perturbation theory, renormalisation and the ongoing coupling. - Concepts and tools for describing QCD in high energy experiments.				
Courses and teaching forms	• Quantum Chromodynamics (Advanced Topic in Particle Physics) (V)				2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	3	28	32	30
	Total workload	3	28	32	30
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	biennial				
Literature	J. Collins, Foundations of Perturbative QCD, Cambridge University Press, 2011 G. Sterman, An Introduction to Quantum Field Theory, Cambridge University Press, 1993				

Module title	**Introduction to Conformal Field Theory**
Module number	PHY-MV-BE-T25
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Theoretische Physik 1-3, Basic knowledge in quantum field theory.
Responsible person	Prof. Dr. Volker Schomerus
Lecturers	Members of the teaching staff from the Department of Physics
Language	English
Qualification objectives	After successful attendance of the lecture, students will be able to read further Literaturee and recent research papers in the field of conformal quantum field theory.
Content	The course provides an introduction to conformal quantum field theories (CFTs), their applications and methods. Topics covered: Conformal symmetry,

	correlation functions, operator product evolutions, 2-dimensional CFT (Virasoro algebra and its representations, minimal models) and conformal bootstrap in dimension d > 2.				
Courses and teaching forms	• Introduction to Conformal Field Theory (V) • Exercises in Introduction to Conformal Field Theory (Ü)				2 SWS 1 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	3	28	32	30
	• Exercises	1	14	16	-
	Total workload	4	42	48	30
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	biennial				
Literature	Weinberg, S, Quantum Field Theory				

Module title	**Computer Algebra and Particle Physics**	
Module number	PHY-MV-BE-T29	
Semester	Wintersemester	
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module	
Prerequisites for participation	Binding: none Recommended: Quantenphysik	
Responsible person	Prof. Dr. Sven-Olaf Moch	
Lecturers	Prof. Dr. Sven-Olaf Moch	
Language	English	
Qualification objectives	Students have basic knowledge of algorithms relevant to theoretical particle physics and experience in working with computer algebra systems.	
Content	Introduction to basic algorithms and computer algebra systems such as Mathematica, Maple or FORM with emphasis on applications in theoretical particle physics; definition and use of expressions, patterns, substitutions and functions; techniques for calculating Feynman integrals. The course includes exercises and hands-on practice with modern software.	
Courses and teaching forms	• Computer Algebra and Particle Physics (V) • Exercises in Computer Algebra and Particle Physics (Ü)	3 SWS 1 SWS

<table>
<tr><td rowspan="4">Workload
(partial performances and total)</td><td></td><td>LP</td><td>P (hrs)</td><td>S (hrs)</td><td>PV (hrs)</td></tr>
<tr><td>• Lecture</td><td>5</td><td>42</td><td>54</td><td>54</td></tr>
<tr><td>• Exercises</td><td>1</td><td>14</td><td>16</td><td>-</td></tr>
<tr><td>Total workload</td><td>6</td><td>56</td><td>70</td><td>54</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Written or oral examination
Language of the exam: English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">biennial</td></tr>
<tr><td>Literature</td><td colspan="5">A. Grozin, Introduction to Mathematica for Physicists, Springer, 2014

J. von zur Gathen and J. Gerhard, Modern Computer Algebra, Cambridge University Press, 2013</td></tr>
</table>

Biomedizinische Physik (Biomedical physics)**:**

Module title	**Biomedical Physics I**
Module number	PHY-MV-BP-E01
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Erika Garutti; Prof. Dr. Florian Grüner
Lecturers	Prof. Dr. Erika Garutti; Prof. Dr. Florian Grüner
Language	English
Qualification objectives	The students know modern methods of medical imaging (PET, SPECT, MRI, CT, multi-modal) and the basic techniques of radiation therapy.
Content	In this course we cover the complex field of different aspects of medical therapy and imaging, with a focus on the latter. In particular, we discuss the physical limitations of current medical imaging techniques and address the question of how physics can add value by pushing the boundaries further. Main aspects are spatial resolution and sensitivity in imaging tumour tissue and / or medical diagnostics. In the Journal Club, these topics are analysed in light of the most modern developments in the fields. Students also learn how to build and discuss a scientific publication.

Courses and teaching forms	• Biomedical Physics I (V) • Journal Club (Ü)				2 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	3	28	32	30
	• Exercises/Journal Club	2	28	32	-
	Total workload	5	56	64	30
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	J. L. Prince and J. M. Links: Medical imaging: signals and systems, Prentice Hall, 2006; C. Grupen and I. Buvat: Handbook of Particle Detection and Imaging; W. R. Leo: Techniques for Nuclear and Particle Physics Experiments, Springer.				

Module title	**Biomedical Physics II**
Module number	PHY-MV-BP-E02
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Arwen Ruth Pearson
Lecturers	Prof. Dr. Arwen Ruth Pearson
Language	English
Qualification objectives	Students know the structure of macromolecules, cells and tissues and with key factors of cellular and extracellular biochemistry related to diseases, including cancer.
Content	In this course we will cover the basics of macromolecular, cellular and tissue structure and architecture from a biophysical perspective. We will cover the basics of metabolism and homeostasis, especially the regulation of the cell cycle, in order to understand the changes at the molecular level associated with the onset of disease. This course aims to put the imaging and detection tools presented in "Biomedical Physics I" into a physiological context. We will also discuss the potential for combined imaging and therapeutic approaches.

	In Journal Club, these topics will be analysed in light of cutting-edge developments in the fields. Students will also learn how to structure and discuss a scientific publication. In particular, the following topics will be presented in the course: - Macromolecular structure and function; - The architecture of the cell; - Biological homeostasis; - The cell cycle; - Metabolic pathways and regulation; - Intra- and intercellular communication; - Therapeutic delivery agents.				
Courses and teaching forms	• Biomedical Physics II (V) • Journal Club (Ü)				2 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	3	28	32	30
	• Exercises/Journal Club	2	28	32	-
	Total workload	5	56	64	30
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	Physical Biology of the Cell, Phillips, Kondev, Theriot & Orme. Garland Scientific.				

Module title	**Biomedical Physics III**
Module number	PHY-MV-BP-E03
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Florian Grüner
Lecturers	Dr. Elisabetta Gargioni
Language	English

Qualification objectives	The students know the basics of radiation transport and its application in radiotherapy and radiation protection. They also have basic knowledge of the role of medical imaging in radiotherapy.				
Content	In this module we will learn the basic aspects of the physics of radiotherapy and radiation protection and focus on radiation transport and dose calculation. The application of multimodal medical imaging in target volume definition and radiation planning will also be discussed and analysed. Participation in the modules "Biomedical Physics I" and "Biomedical Physics II" are not prerequisites for this module. The following aspects are covered here: - Interactions of photons and charged particles with matter - Basics of radiation transport and Monte Carlo techniques - Basics of computed tomography, PET/SPECT and MRI - Multimodal imaging in radiotherapy - Target volume definition and irradiation techniques - Basics of radiation treatment planning				
Courses and teaching forms	• Biomedical Physics III (V)				2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	3	28	32	30
	Total workload	3	28	32	30
Study / Examination achievements	Type of examination: Oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	Annually				
Literature	P. Mayles, A. Nahum, J. C. Rosenwald (Eds.), Handbook of Radiotherapy Physics – Theory and Practice, Taylor & Francis (2007); M. Goitein, Radiation Oncology: A Physicist's-Eye View, Springer (2008).				

Module title	**Biomedical Physics IV**
Module number	PHY-MV-BP-E04
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Florian Grüner

<table>
<tr><td>Lecturers</td><td colspan="5">Dr. Elisabetta Gargioni</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">The students know the basics of the physics of radiation therapy. They also have basic knowledge of the physical and biological optimisation of a radiation treatment plan and the application of different radiation techniques and treatment concepts for some tumour entities.</td></tr>
<tr><td>Content</td><td colspan="5">In this module you will gain an insight into the fundamental aspects of physics in radiotherapy and mathematical modelling in radiobiology, with a focus on radiation techniques and therapy concepts. Building on the content of the module "Biomedical Physics III", we will discuss and analyse the current state of radiation planning, radiation techniques and application of multimodal imaging in radiotherapy, especially of moving tumours.
During a practical evening session at the Department of Radiotherapy and Radiation Oncology, students will have the opportunity to record the basic measurement data for the dosimetric characterisation of a medical linear accelerator and analyse the results.
The following aspects will be covered:
- Radiation techniques and new treatment methods in modern radiotherapy.
- Optimisation techniques for radiation treatment planning
- Dosimetry and quality assurance in radiotherapy
- Treatment of mobile tumours
- Basics of fractionation and of the five “R” in radiotherapy</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Biomedical Physics IV (V)</td><td>2 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>• Lecture</td><td>LP
3</td><td>P (hrs)
28</td><td>S (hrs)
32</td><td>PV (hrs)
30</td></tr>
<tr><td>Total workload</td><td>3</td><td>28</td><td>32</td><td>30</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Oral examination
Language of the exam: English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">annually</td></tr>
<tr><td>Literature</td><td colspan="5">P. Mayles, A. Nahum, J. C. Rosenwald (Eds.), Handbook of Radiotherapy Physics – Theory and Practice, Taylor & Francis (2007);
M. Goitein, Radiation Oncology: A Physicist’s-Eye View, Springer (2008).</td></tr>
</table>

Module title	**Seminar on Biomedical Physics I**
Module number	PHY-MV-BP-E05

Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Erika Garutti; Prof. Dr. Florian Grüner
Lecturers	Prof. Dr. Erika Garutti; Prof. Dr. Florian Grüner
Language	English
Qualification objectives	Students have the knowledge of modern methods of imaging in medicine (PET, SPECT, MRI, CT, multimodal) and the basic techniques of radiotherapy.
Content	In this seminar series, six experts will present six relevant topics in biomedical physics. The topics will be presented from the point of view of a doctor (concrete application of techniques in medical cases) or industrial producers (relevance of research from the point of view of industrialisation). (The seminar complements the module "Biomedial Physics I" (PHY-MV-BP-E01). It is divided into two parts: The first part is an introduction to the field by experts from UKE and major companies that develop and produce medical imaging tools. The second part is the presentation of related topics by the course participants).
Courses and teaching forms	• Seminar on Biomedical Physics I (S) — 2 SWS

Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Seminar	3	28	32	30
	Total workload	3	28	32	30

Study / Examination achievements	Type of examination: Referat mit schriftlicher Ausarbeitung Language of the exam: English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	annually
Literature	To be announced in the course.

Festkörper- und Nanostrukturphysik (Solid state and nanostructure physics):

Module title	**Advanced Solid State Lecture**
Module number	PHY-MV-FN-E01

<table>
<tr><td>Semester</td><td colspan="5">Summersemester</td></tr>
<tr><td>Applicability, module type and assignment to the curriculum</td><td colspan="5">• Nanowissenschaften (M.Sc.): Compulsory elective module
• Physik (M.Sc.): Compulsory elective module
• Physics (M.Sc.): Compulsory elective module</td></tr>
<tr><td>Prerequisites for participation</td><td colspan="5">Binding: none
Recommended: Physik IV (= Festkörperphysik) or
Nanostrukturphysik A und B</td></tr>
<tr><td>Responsible person</td><td colspan="5">Prof. Dr. Robert H. Blick; Prof. Dr. Michael Rübhausen</td></tr>
<tr><td>Lecturers</td><td colspan="5">Prof. Dr. Robert H. Blick; Prof. Dr. Michael Rübhausen</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">The students have in-depth knowledge of the scientific status of research in solid state and nanostructure physics. They have in-depth knowledge to be able to successfully carry out an experimental Master's thesis in the field of solid state and nanostructure physics.</td></tr>
<tr><td>Content</td><td colspan="5">The scope of the material includes:
- Boltzmann classical charge and heat transport, localisation, interference effects, Coulomb blockade in nanostructures, spin transport;
- Dielectric function of solids and nanostructures, elementary excitations such as plasmons, polarons, polaritons, excitons, magnons;
- Metal-insulator transitions (Mott insulator, Hubbard model);
- Correlated electron systems using the example of high-temperature superconductors and manganates;
- Giant magnetoresistance and spin currents (interlayer exchange coupling, spin valves and exchange bias, Rashba effect).
Furthermore, they will be familiarised with current formalisms for the theoretical description of modern solids, as far as they are necessary for the experimental understanding (Fermis-Golden rule, susceptibilities, response theory, propagators) and they will be introduced to current issues in solid state and nanostructure physics and their experimental methods. Key experiments and applications of new materials such as graphene or topological insulators are taught on the basis of selected current specialist publications, which the students deal with in the course.</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Advanced Solid State Lecture (V)
• Exercises in Advanced Solid State Lecture (Ü)</td><td>4 SWS
2 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>
• Lecture
• Exercises</td><td>LP
6
2</td><td>P (hrs)
56
28</td><td>S (hrs)
62
32</td><td>PV (hrs)
62
-</td></tr>
<tr><td>Total workload</td><td>8</td><td>84</td><td>94</td><td>62</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Written or oral examination
Language of the exam: English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
</table>

Frequency of the course	annually
Literature	To be announced in the course.

Module title	**Nanostructure Physics I**				
Module number	PHY-MV-FN-E02				
Semester	Wintersemester				
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: Nanostrukturphysik A oder Physik IV (= Festkörperphysik)				
Responsible person	Prof. Dr. Dorota Koziej				
Lecturers	Prof. Dr. Dorota Koziej				
Language	English				
Qualification objectives	Students will be able to summarise the main research results on the synthesis of and research on semiconductor nanostructures and devices.				
Content	▪ Semiconductors: Fundamentals and charge carrier transport ▪ Interfaces in semiconductors, classical semiconductor devices ▪ Molecular beam epitaxy, self-organisation, HL quantum dots ▪ Transport in low-dimensional electron systems ▪ Nanoplasmonics ▪ Metamaterials ▪ Semiconductor nanoparticles and quantisation effects ▪ Semiconductor Nanorods and Devices ▪ Thermoelectric nanostructures ▪ Graphene, Carbon Nanotubes and Organic Semiconductors				
Courses and teaching forms	• Nanostructure Physics I (V) • Exercises in Nanostructure Physics I (Ü)				4 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	6	56	62	62
	• Exercises	2	28	32	-
	Total workload	8	84	94	62
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				

Literature	To be announced in the course.

Module title	**Nanostrukturphysik II: Oberflächenphysik und Magnetismus**
Module number	PHY-MV-FN-E04
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Festkörperphysik und Quantenmechanik (Physik III)
Responsible person	Prof. Dr. Roland Wiesendanger
Lecturers	PD Dr. Kirsten von Bergmann, PD Dr. Jens Wiebe
Language	English (Deutsch, falls alle Teilnehmer dies wünschen)
Qualification objectives	After successfully completing this module the students will have a good overview of both fundamentals and current research in the fields of surface science, electronic structure and magnetism in reduced dimensions, and spintronics. A focus of this lecture will be put on magnetic atoms, nanostructures, and films on single crystal surfaces. The students will be able to understand experimental sample preparation procedures as well as experimental techniques of low-temperature physics and different surface science characterization tools, such as for instance spin-sensitive scanning probe methods. They will be able to identify different magnetic interactions responsible for the emergence of magnetic order and will have an overview of the different theoretical tools needed for the understanding and prediction of complex magnetic states including their dynamics. Finally, they will be able to connect the topics to current research activities like, e.g., topological materials, magnetic skyrmions, and magnet-superconductor hybrid systems. Students will be eligible to perform the Nanostrukturphysik II - Vertiefungspraktikum either during the module or anytime afterwards.
Content	- Ultra-high-vacuum and low temperature technology - Surface structures, including superstructures - Surface characterization tools using electrons or photons - Scanning probe methods including spin- and time-resolved variants - Magnetoresistance effects - Complex magnetic order including spin spirals and skyrmions - Surface electronic structure including surface states and Rashba effects - Dimensionality effects on band magnetism

<table>
<tr><td></td><td colspan="5">- Generalized Heisenberg models in quantum mechanical and semiclassical descriptions including crystal field anisotropy and exchange interactions
- Role of spin-orbit coupling in surface magnetism
- Magnetization dynamics: precession, spin waves, Landau-Lifschitz-Gilbert equation
- Recent hot topics: topological insulators, magnetic skyrmions, topological superconductors, Majorana bound states</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Nanostrukturphysik II (V)
• Übungen zur Nanostrukturphysik II (Ü)</td><td>4 SWS
2 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>
• Lecture
• Exercises</td><td>LP
6
2</td><td>P (hrs)
56
28</td><td>S (hrs)
62
32</td><td>PV (hrs)
62
-</td></tr>
<tr><td>Total workload</td><td>8</td><td>84</td><td>94</td><td>62</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Written or oral examination
Language of the exam: German or English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">annually</td></tr>
<tr><td>Literature</td><td colspan="5">Festkörperphysik, R. Gross und A. Marx (De Gruyter 2014)
Festkörperphysik, S. Hunklinger (De Gruyter Oldenbourg)
Tieftemperaturphysik, C. Enss und S. Hunklinger (Springer 2000)
Magnetism in Condensed Matter, S. Blundell (Oxford University Press)
Simple Models of Magnetism, R. Skomski (Oxford Graduate Texts)
Magnetism, J. Stöhr und H.C. Siegmann (Springer)
Physics of Ferromagnetism, S. Chikazumi (Oxford Science Publications)
Surface Physics: An Introduction, P. Hofmann (e book only 2016)
Oberflächenphysik des Festkörpers, M. Henzler / W. Göpel (Teubner 1994)
Physics of Surfaces and Interfaces, H. Ibach (Springer 2006)
Scanning Probe Microscopy and Spectroscopy, R. Wiesendanger (Cambridge University Press)</td></tr>
</table>

Module title	**Nanostrukturphysik IV - Energiematerialien und Nanobiotechnologie**
Module number:	PHY-MV-FN-E11
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module

Prerequisites for participation	Binding: none Recommended: none				
Responsible person:	Prof. Dr. Robert H. Blick; Prof. Dr. Arwen Ruth Pearson				
Lecturers	Prof. Dr. Robert H. Blick; Prof. Dr. Arwen Ruth Pearson				
Language	German or English				
Qualification objectives	After successfully completing the module, students will be able to summarise the main research results on energy storage and energy generation using nanomaterials or the application of nanostructures and nanomaterials in the fields of medicine and biotechnology.				
Content	Current research results are to be presented in regular rotation, alternating between the two thematic fields of energy materials or nanobiotechnology, with particular emphasis on the interdisciplinary aspects within the nanosciences with the thematic fields of physics, chemistry, biology, engineering sciences and medicine.				
Courses and teaching forms	• Nanostrukturphysik IV (V) • Übungen zur Nanostrukturphysik IV (Ü)				2 SWS 1 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	3	28	32	30
	• Exercises	1	14	16	-
	Total workload	4	42	48	30
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature:	To be announced in the course.				

Module title	**Advanced Methods for Surface and Nanostructure Characterization**
Module number	PHY-MV-FN-E12
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Festkörperphysik; Nanostrukturphysik
Responsible person	Prof. Dr. Andreas Stierle

<table>
<tr><td>Lecturers</td><td colspan="5">Prof. Dr. Andreas Stierle</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">The students have the understanding of different methods for the structural and chemical characterisation of nanostructures and surfaces as well as the development of decision-making competence for the choice of methods for the chemical and structural characterisation of nanostructures and surfaces.
After successful completion of the module, students know how to characterise the atomic structure of surfaces and nanostructures using X-ray and electron diffraction methods.
They know different methods to describe the morphology, atomic structure or near order.
Furthermore, the students know electron spectroscopic methods that are used to characterise the chemical and electronic properties. Finally, they have an overview of spatially resolving scanning probe techniques.</td></tr>
<tr><td>Content</td><td colspan="5">I. X-ray diffraction on systems with reduced dimensions
- X-ray reflection
- X-ray diffraction under grazing incidence, small angle scattering
- Surface X-ray diffraction
- Diffraction from thin films, multilayers and nanoparticles
II. electron diffraction in low-dimensional systems
- Diffraction of low-energy electrons
- Diffraction of high energy electrons
- Electrons as a local probe: EXAFS
III. surface sensitive spectroscopy
- Photoemission spectroscopy
- Auger electron spectroscopy
IV. Scanning probe techniques
- Scanning tunneling microscopy
- Atomic force microscopy
- Scanning electron microscopy</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Advanced Methods for Surface and Nanostructure Characterization (V)
• Exercises in Advanced Methods for Surface and Nanostructure Characterization (Ü)</td><td>2 SWS
2 SWS</td></tr>
<tr><td rowspan="4">Workload
(partial performances and total)</td><td></td><td>LP</td><td>P (hrs)</td><td>S (hrs)</td><td>PV (hrs)</td></tr>
<tr><td>• Lecture</td><td>3</td><td>28</td><td>32</td><td>30</td></tr>
<tr><td>• Exercises</td><td>2</td><td>28</td><td>32</td><td>-</td></tr>
<tr><td>Total workload</td><td>5</td><td>56</td><td>64</td><td>30</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Written or oral examination
Language of the exam: English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
</table>

Frequency of the course	annually
Literature	1. J. Als-Nielsen, D. Mc Morrow, Elements of modern x-ray physics, Wiley 2. H. Dosch, critical phenomena at surfaces and interfaces, Springer 3. G. Ertl, J. Küppers, Low energy electron diffraction and surface chemistry, Springer 4. K. Wandelt, surface and interface science, Wiley 5. R. Waser, nanoelectronics and information technology, Wiley 6. E. Mittemeijer, U, Welzel, modern diffraction methods, Wiley

Module title	**Seminar über Nahfeldgrenzflächenphysik und Nanotechnologie**				
Module number	PHY-MV-FN-E16				
Semester	Sommer- und Wintersemester				
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: Physik IV (= Festkörperphysik) oder Nanostrukturphysik A und B				
Responsible person	Prof. Dr. Roland Wiesendanger				
Lecturers	Prof. Dr. Roland Wiesendanger				
Language	German or English				
Qualification objectives	Students have in-depth knowledge of and insight into current developments in research in solid state and nanostructure physics. Students know modern solid state and nanostructure physics, by addressing current questions using experimental methods. They have in-depth knowledge to be able to successfully carry out a Master's thesis in the field of experimental solid state and nanostructure physics.				
Content	Deepening of current topics in solid state and nanostructure physics Experimental methods of solid state and nanostructure physics				
Courses and teaching forms	• Seminar über Nahfeldgrenzflächenphysik und Nanotechnologie (S)				2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Seminar	3	28	32	30
	Total workload	3	28	32	30

Study / Examination achievements	Type of examination: Referat Language of the exam: German or English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	every semester
Literature	To be announced in the course.

Module title	**Bio- and Nanointerfaces**
Module number	PHY-MV-FN-E18
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Grundlagen der physikalischen Chemie
Responsible person	Prof. Dr. Robert H. Blick
Lecturers	Prof. Dr. Robert H. Blick; PD Dr. Thomas F. Keller
Language	German or English
Qualification objectives	The students have basic knowledge of important bio-physical processes at interfaces and have a fundamental and interdisciplinary understanding for further lectures and theses in this interdisciplinary field. After successfully completing the module, the students know how cells transmit electrical signals, how ion channels and nanopores function and what influence an interface has on the conformation of a protein. They know applications in the field of microfluidics, sensor technology and biomedicine as well as methods for the investigation of bio-physical processes, with the help of which current scientific questions can be answered.
Content	I Introduction II Basics - Force and energy - Thermodynamic potentials - Diffusion - Debye-Hückel shielding, zeta potential III Bio- and nano-interfaces - Physical description of organic and inorganic interfaces - Biophysical interfaces - Surface tension and osmosis

	- Cell membranes - Electrical properties of cell membranes and ion transfer - Structure and spatial structure of proteins - Protein-protein / protein-surface interactions - AFM force spectroscopy: force-induced secondary structure changes - Enzyme catalysis by tunnel effect VI Applications - Microfluidics - Implant surfaces in research - Bioelectronic devices - Biosensors and in-vitro/in-vivo diagnostics				
Courses and teaching forms	• Bio-Nano-Interfaces (V)				2 SWS
Workload (partial performances and total)	• Lecture	LP 3	P (hrs) 28	S (hrs) 32	PV (hrs) 30
	Total workload	3	28	32	30
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	„Biophysics: A Physiological Approach“, Patrick F. Dillon, Cambridge University Press, 2012. „Bioelectronics Handbook: MOSFETs, Biosensors, and Neurons“, Massobrio, Giuseppe, McGraw-Hill Companies, 1998. MIT Open course ware http://ocw.mit.edu/courses/materials-science-and-engineering/(3-051j) „Intermolecular and Surface Forces“, 2nd ed., J.N. Israelachvili, Academic Press, London, 1992. „Biomaterials: Protein–Surface Interactions“, R.A. Latour, in Encyclopedia of Biomaterials and Biomedical Engineering, 2005.				

Module title	**X-Ray Analytics and Microscopy in Nanoscience**
Module number	PHY-MV-FN-E23
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module

Prerequisites for participation	Binding: none Recommended: none				
Modulverantwortliche®	Prof. Dr. Christian Schroer				
Lecturers	Prof. Dr. Christian Schroer				
Language	English				
Qualification objectives	Students will be able to summarise the essential current X-ray analytical and X-ray microscopic methods for the investigation of functional nanomaterials.				
Content	The following topics will be covered: - Interaction of X-rays with matter - Wave optics of X-rays and X-ray optics - tomography - Scanning microscopy and analysis X-ray fluorescence, absorption, diffraction - Imaging X-ray microscopy - Imaging with coherent X-rays				
Courses and teaching forms	• X-Ray Analytics and Microscopy in Nanoscience (V)				2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	3	28	32	30
	Total workload	3	28	32	30
Study / Examination achievements	Type of examination: Hausarbeit Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	Wird in der Lehrveranstaltung bekannt gegeben.				

Module title	**Die Kunst der Computer-basierten Modellierung und Simulation experimenteller Daten**
Module number	PHY-MV-FN-E31
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module

<table>
<tr><td>Prerequisites for participation</td><td colspan="5">Binding: none
Recommended: none</td></tr>
<tr><td>Responsible person</td><td colspan="5">Prof. Dr. Michael Rübhausen</td></tr>
<tr><td>Lecturers</td><td colspan="5">Prof. Dr. Michael Rübhausen; Dr. Benjamin Grimm-Lebsanft</td></tr>
<tr><td>Language</td><td colspan="5">German or English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">The students have an understanding of mathematical descriptions of experimental data with explicit consideration of numerical and experimental errors.
They know the basics of statistics, numerics and programming as well as the modelling of an experimental data set.</td></tr>
<tr><td>Content</td><td colspan="5">- Statistics - Revision of the basics
- Numerics: Integrating, differentiating, FFT, solving a linear system of equations
- DGL's: Runge Kutta
- Fit algorithms considering experimental errors: Linear function; Gauss-Newton method; Levenberg Mar-quardt; Monte-Carlo
- Stability of a fit under consideration of experimental errors
- Global versus local fit minimum</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Die Kunst der Computer-basierten Modellierung und Simulation experimenteller Daten (V)
• Übungen zur Kunst der Computer-basierten Modellierung und Simulation experimenteller Daten (Ü)
• Computerübungen zur Kunst der Computer-basierten Modellierung und Simulation experimenteller Daten (CÜ)
• Projekt zur Kunst der Computer-basierten Modellierung und Simulation experimenteller Daten (Pj)</td><td>2 SWS
2 SWS
2 SWS
1 SWS</td></tr>
<tr><td rowspan="3">Workload
(partial performances and total)</td><td></td><td>LP</td><td>P (hrs)</td><td>S (hrs)</td><td>PV (hrs)</td></tr>
<tr><td>• Lecture
• Exercises
• Computerexercises
• Project</td><td>3
2
2
2</td><td>28
28
28
14</td><td>32
16
16
23</td><td>30
16
16
23</td></tr>
<tr><td>Total workload</td><td>9</td><td>98</td><td>87</td><td>85</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Project completion
Language of the exam: German or English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">annually</td></tr>
<tr><td>Literature</td><td colspan="5">Numerical Recipes – The Art of Scientific Computing (3rd Edition)</td></tr>
</table>

Module title	Quantentransport und experimentelle Quantenphysik
Module number	PHY-MV-FN-E32
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Grundlagen der Elektrodynamik und Quantenmechanik
Responsible person	Prof. Dr. Robert H. Blick
Lecturers	Prof. Dr. Robert H. Blick; Dr. Lars Tiemann
Language	German or English
Qualification objectives	The students have an in-depth knowledge of the important principles of semiconductor and solid-state physics and fundamental knowledge of new, exotic states of matter. They have an understanding of important quantum effects in solids and their experimental investigation methods. The students know how modern semiconductor structures are constructed and how they can be processed into nanostructures. They understand under which conditions quantum effects occur in semiconductors, how they are to be interpreted physically and how they are investigated experimentally. The students know the applications of modern measurement techniques of semiconductors at temperatures $\leqslant$ 4.2 Kelvin and have the necessary basics to be able to work experimentally in the field of quantum transport.
Content	I Introduction II Fundamentals of solid state and semiconductor physics (approx. 15% of the VL) - band structures - Properties of charge carriers III Fundamentals of semiconductor technology (approx. 15%) - Growth of semiconductors - Processing, structuring and clean room technologies - Characterisation methods IV Quantum effects and quantum transport (approx. 60%) - Transport of charge carriers - Interactions and defects - Quantisation by confinement potentials and magnetic fields - Quantum Hall effects and graphene - Topological systems - Quantum effects in nanostructures V Measurement Methods and Technologies (approx. 10%)

	- Fundamentals of low-temperature physics (4.2 Kelvin to millikelvin range) - Fundamentals of measurement data acquisition for transport at low temperatures (Measurement methods and data acquisition/programming)				
Courses and teaching forms	• Quantentransport und experimentelle Quantenphysik (V) • Seminar zu Quantentransport und experimentelle Quantenphysik (S)				2 SWS 1 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Seminar	3 1	28 14	32 8	30 8
	Total workload	4	42	40	38
Study / Examination achievements	Type of examination: Presentation or oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	„Semiconductor Nanostructures: Quantum states and electronic transport“, Thomas Ihn, Oxford Univ. Press, 2011 "The physics of low-dimensional semiconductors: an introduction", John H. Davies, Cambridge Univ. Press, 2009 „Semiconductor spintronics“, Thomas Schäpers, De Gruyter, 2016 "Introduction to the Physics of Electrons in Solids", Henri Alloul, Springer-Verlag, 2011				

Module title:	**Modern Scattering Methods in Nanomaterial Science**
Module number:	PHY-MV-FN-E33
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation:	Binding: none Recommended: Nanochemie I & II, Methoden moderner Röntgenphysik I
Responsible person:	Prof. Dr. Dorota Koziej
Lecturers:	Mads Ry Jørgensen, AU Dorota Koziej, UHH Ann-Christin Dippel, DESY

<table>
<tr><td>Language:</td><td colspan="5">English</td></tr>
<tr><td>Qualification objectives:</td><td colspan="5">The students know the theoretical background and have practical experience with synchrotron X-ray scattering techniques relevant for the characterisation of nanoparticles.
In detail:
- Consider the properties of synchrotron radiation for the structural study of nanoparticles.
- Explain the principle of small angle X-ray scattering (SAXS), powder X-ray diffraction (PXRD) and total scattering (TS).
- Identify the main technical components in the experimental set-ups and consider their effects on the resulting data
- Perform analyses of SAXS, PXRD and TS data from nanoparticles.
- Discuss the strengths and weaknesses of the three methods for characterising the properties of nanoparticles</td></tr>
<tr><td>Content:</td><td colspan="5">- Nanoparticle synthesis and sample preparation in the lab.
- The theory and principles behind PXRD, SAXS & TS and data analysis will be presented in a series of lectures and exercises.
- Experiments on two beamlines at the German Electron Synchrotron (DESY). Students will perform experiments in small groups on their own samples.
- The data collected during the experiments will be analysed during the workshops.</td></tr>
<tr><td>Courses and teaching forms:</td><td colspan="4">• Modern Scattering Methods in Nanomaterial Science (V)
• Sample preparation and synchrotron experiments (P)
• Data analysis (Ü)</td><td>1 SWS
2 SWS
2 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>
• Lectures & e-learning (V)
• Experiments (P)
• Data analysis (Ü)</td><td>LP
2
2
1</td><td>P(hrs)
14
28
28</td><td>S (hrs)
24
16
2</td><td>PV (hrs)
22
16
-</td></tr>
<tr><td>Total</td><td>5</td><td>70</td><td>42</td><td>38</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Referat mit schriftlicher Ausarbeitung
Language of the exam: English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">annually</td></tr>
<tr><td>Literature:</td><td colspan="5">To be announced in the course.</td></tr>
</table>

Module title	**Methods in Nanobiotechnology II**
Module number	PHY-MV-FN-E34
Semester	Summersemester

Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: none				
Responsible person	Prof. Dr. Wolfgang Parak				
Lecturers	Prof. Wolfgang Parak; Dr. Neus Feliu; Dr. Florian Schulz				
Language	English				
Qualification objectives	The students have knowledge of modern methods and aspects of nanobiotechnology. They are prepared for scientific work in this topic and can understand, classify and also summarize technical primary Literaturee on the topic.				
Content	In this course, basic methods of nanobiotechnology are presented and discussed. The focus of this module is on the synthesis of materials, especially colloids, and their characterization. Experimental techniques and background information on measurement applications will be covered. Examples covered include synthesis of colloidal nanoparticles and microparticles, functionalization of surfaces, purification methods, determination of particle sizes and particle separation processes, bioconjugation, photophysical principles, etc.				
Courses and teaching forms	• Methods in Nanobiotechnology II (V) • Exercises in Methods in Nanobiotechnology II (Ü) • Practical: Methods in Nanobiotechnology II (P)				2 SWS 2 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises • Praktikum	3 2 2	28 28 28	32 32 32	30 - -
	Total workload	7	84	96	30
Study / Examination achievements	Type of examination: Presentation (50%) and oral examination (50%) Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	To be announced in the course.				

Module title	Fundamentals of Photovoltaics
Module number	PHY-MV-FN-E35
Semester	Summersemester

Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: Physik V				
Responsible person	Prof. Dr. Christian Schroer				
Lecturers	Members of the teaching staff from the Department of Physics				
Language	English				
Qualification objectives	Students are familiar with the concept of photovoltaic power generation and are prepared for scientific work in this field.				
Content	The following topics will be covered: - Concept of photovoltaic energy generation - Theoretical, technical and economic limits of photovoltaics - Technology of different types of solar cells - Fabrication of solar cells				
Courses and teaching forms	• Fundamentals of Photovoltaics (V)				2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	3	28	32	30
	Total workload	3	28	32	30
Study / Examination achievements	Type of examination: Written draft Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	To be announced in the course.				

Module title	**Complex Materials**
Module number	PHY-MV-FN-E36
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (B.Sc.) (nur 6. FS): Compulsory elective module • Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module

Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Dorota Koziej
Lecturers	Prof. Dr. Dorota Koziej
Language	English
Qualification objectives	Students know the theoretical background and have acquired practical experience with complex materials.
Content	The course is divided into three parts: I) Synthesis of 0-, 1-, 2- and 3-dimensional building blocks with a length scale from nm to µm. Including practical aspects of batch and flow chemistry. II) Assembly of building blocks into 1-, 2-, and 3-dimensional complex structures over multiple length scales up to cm. In Part I, various methods for synthesis of inorganic and polymeric building blocks are discussed. Part II focuses on self- and directional assembly methods, dispersion-based coating, 2D and 3D ink printing that can be used to create higher order architectures from those building blocks that connect the microscopic to the macroscopic world and their applications. Part III focuses on applying the concepts learned to a problem of modern functional materials. This includes the implementation of the students' own ideas in the laboratory.
Courses and teaching forms	• Complex Materials (V) — 3 SWS • Project (Pj) — 2 SWS

Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	4	42	40	38
	• Project	2	28	32	-
	Total workload	6	84	94	62

Study / Examination achievements	Studienleistung: Project completion Type of examination: Referat mit schriftlicher Ausarbeitung Language of the exam: English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	annually
Literature	To be announced in the course.

Module title	**Wahlpflichtpraktikum Physik**
Module number	PHY-MV-FN-E37
Semester	Wintersemester and Summersemester

<table>
<tr><td>Applicability, module type and assignment to the curriculum</td><td colspan="5">Nanowissenschaften (M.Sc.): Compulsory elective module
Physik (M.Sc.): Compulsory elective module
Physics (M.Sc.): Compulsory elective module</td></tr>
<tr><td>Prerequisites for participation</td><td colspan="5">Binding: none
Recommended: none</td></tr>
<tr><td>Responsible person</td><td colspan="5">Members of the group of university professors of the Department of Physics.</td></tr>
<tr><td>Lecturers</td><td colspan="5">Members of the teaching staff from the Department of Physics</td></tr>
<tr><td>Language</td><td colspan="5">German or English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">Possession of knowledge and application of modern and sophisticated methods or knowledge of modern techniques and procedures. The students possess the key qualifications (in particular methodological competence, work planning, social competence/teamwork, preparation of documentation, practice of a scientific presentation, literary research) in connection with physical contents.</td></tr>
<tr><td>Content</td><td colspan="5">The elective internship can be done in a physics research group of the student's choice.</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">i.d.R. (P) + (S)</td><td>6-15 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>Practical lab course mit Seminar</td><td>LP
6-15</td><td>P (hrs)
140-340</td><td>S (hrs)
20-55</td><td>PV (hrs)
20-55</td></tr>
<tr><td>Total workload</td><td>6-15</td><td>140-340</td><td>20-55</td><td>20-55</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Completion of the internship (presentation and/or written paper)
Language of the exam: German or English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">every semester</td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

Module title	**Methods in Nanobiotechnology I**
Module number	PHY-MV-FN-E39
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module

<table>
<tr><td>Prerequisites for participation</td><td colspan="5">Binding: none
Recommended: none</td></tr>
<tr><td>Responsible person</td><td colspan="5">Prof. Dr. Wolfgang Parak</td></tr>
<tr><td>Lecturers</td><td colspan="5">Prof. Wolfgang Parak; Dr. Neus Feliu; Dr. Florian Schulz</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">The students know modern methods and aspects of nanobiotechnology and are prepared for scientific work in this topic. The students are able to understand and classify technical primary Literaturee on the topic and also present it in summary form.</td></tr>
<tr><td>Content</td><td colspan="5">In this course, basic methods of nanobiotechnology are presented and discussed. The focus of this module is on the synthesis of materials, especially colloids, and their characterization. Experimental techniques and background information on measurement applications will be covered. Examples covered include synthesis of colloidal nanoparticles and microparticles, functionalization of surfaces, purification methods, determination of particle sizes and particle separation processes, bioconjugation, photophysical principles, etc.</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Methods in Nanobiotechnology I (V)
• Exercises in Methods in Nanobiotechnology I (Ü)
• Practical: Methods in Nanobiotechnology I (P)</td><td>2 SWS
2 SWS
2 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>• Lecture
• Exercises
• Practical lab course</td><td>LP
3
2
2</td><td>P (hrs)
28
28
28</td><td>S (hrs)
32
32
32</td><td>PV (hrs)
30
-
-</td></tr>
<tr><td>Total workload</td><td>7</td><td>84</td><td>96</td><td>30</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Presentation (50%) and oral examination (50%)
Language of the exam: English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">annually</td></tr>
<tr><td>Literature</td><td colspan="5">To be announced in the course.</td></tr>
</table>

Module title	**Nonequilibrium Statistics and Transport Theory**
Module number	PHY-MV-FN-T13
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module

Prerequisites for participation	Binding: none Recommended: none				
Responsible person	Prof. Dr. Michael Thorwart				
Lecturers	Prof. Dr. Michael Thorwart/ PD Dr. Alexander Chudnovskiy				
Language	English				
Qualification objectives	Students are familiar with modern concepts in quantum statistics of systems in non-equilibrium and quantum transport theory and are prepared for scientific work in this field.				
Content	Modern concepts of quantum statistics of systems in nonequilibrium and quantum transport theory.				
Courses and teaching forms	• Nonequilibrium Statistics and Transport Theory (V) • Exercises in Nonequilibrium Statistics and Transport Theory (Ü)				4 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	6 2	56 28	62 32	62 -
	Total workload	8	84	94	62
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	biennial				
Literature	To be announced in the course.				

Module title	**Theorie der kondensierten Materie I**
Module number	PHY-MV-FN-T14
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Daniela Pfannkuche
Lecturers	Members of the teaching staff from the Department of Physics
Language	German or English

Qualification objectives	Students will have the basic knowledge and experience in using typical methods of condensed matter theory.				
Content	- Electrons in crystals - Electronic band structure - Electron dynamics in crystals - phonons - Superconductivity				
Courses and teaching forms	• Theorie der kondensierten Materie I (V) • Übungen zur Theorie der kondensierten Materie I (Ü)				4 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	6	56	62	62
	• Exercises	2	28	32	-
	Total workload	8	84	94	62
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	To be announced in the course.				

Module title	**Seminar on Selected Topics of the Quantum Theory of Condensed Matter**
Module number	PHY-MV-FN-T17
Semester	Wintersemester/ Summersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Daniela Pfannkuche
Lecturers	Prof. Dr. Daniela Pfannkuche
Language	English
Qualification objectives	Students have basic knowledge of modern topics and methods in condensed matter theory. They are able to synthesize knowledge from contemporary scientific publications and reproduce it in a scientific presentation. Students have in-depth knowledge of selected current topics in condensed matter theory and can actively contribute to scientific discussions.

Content	Current aspects and novel developments of quantum many-body theory: novel materials and advanced methods.				
Courses and teaching forms	• Seminar on Selected Topics of the Quantum Theory of Condensed Matter (S)				2 SWS
Workload (partial performances and total)	• Seminar	LP 3	P (hrs) 28	S (hrs) 32	PV (hrs) 30
	Total workload	3	28	32	30
Study / Examination achievements	Type of examination: Referat mit schriftlicher Ausarbeitung Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	every semester				
Literature	To be announced in the course.				

Module title	**Seminar on Many-Body Theory and Quantum-Statistical Methods**				
Module number	PHY-MV-FN-T18				
Semester	Wintersemester/ Summersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module • Nanowissenschaften (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: none				
Responsible person	Prof. Dr. Michael Potthoff				
Lecturers	Prof. Dr. Michael Potthoff				
Language	English				
Qualification objectives	Students will be able to discuss current physical problems in the field of many-particle theory and quantum statistical methods, and to develop and present a specialized topic.				
Content	Novel research directions on many-body theory and quantum statistical methods.				
Courses and teaching forms	• Seminar on Many-Body Theory and Quantum-Statistical Methods (S)				2 SWS
Workload	• Seminar	LP 3	P (hrs) 28	S (hrs) 32	PV (hrs) 30

(partial performances and total)	Total workload	3	28	32	30
Study / Examination achievements	Type of examination: Referat mit schriftlicher Ausarbeitung Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	every semester				
Literature	To be announced in the course.				

Module title	**Seminar on Quantum Dynamics of Nonequilibrium Nano Systems**				
Module number	PHY-MV-FN-T19				
Semester	Wintersemester/ Summersemester				
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: none				
Responsible person	Prof. Dr. Michael Thorwart				
Lecturers	Prof. Dr. Michael Thorwart				
Language	English				
Qualification objectives	Students are familiar with current research topics in the field and are prepared for scientific work.				
Content	Scientific analysis of current issues in quantum statistics of systems in non-equilibrium and quantum transport.				
Courses and teaching forms	• Seminar on Quantum Dynamics of Nonequilibrium Nano Systems (S)				2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Seminar	3	28	32	30
	Total workload	3	28	32	30
Study / Examination achievements	Type of examination: Referat mit schriftlicher Ausarbeitung Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	every semester				
Literature	To be announced in the course.				

Module title	**Quantum Statistics with Path Integrals**				
Module number	PHY-MV-FN-T24				
Semester	Summersemester				
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: none				
Responsible person	Prof. Dr. Michael Thorwart				
Lecturers	Prof. Dr. Michael Thorwart				
Language	English				
Qualification objectives	Students will be familiar with current methods in the field of path integrals for quantum many-body systems and will be prepared for scientific work.				
Content	- Advanced introduction to quantum statistics with path integrals - Current methods from the field of path integrals for quantum many-particle systems				
Courses and teaching forms	• Quantum Statistics with Path Integrals (V) • Exercises in Quantum Statistics with Path Integrals (Ü)				4 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	6	56	62	62
	• Exercises	2	28	32	-
	Total workload	8	84	94	62
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	biennial				
Literature	To be announced in the course.				

Module title	**Symmetry Groups in Physics**
Module number	PHY-MV-FN-T25
Semester	Wintersemester

Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Theoretische Physik I, Theoretische Physik II
Responsible person	Prof. Dr. Michael Potthoff
Lecturers	Prof. Dr. Michael Potthoff
Language	English
Qualification objectives	Students will be familiar with basic tools of group theory and will be able to apply group theory concepts in different fields of theoretical physics.
Content	- Symmetry concepts in various fields of physics. - Basic concepts of mathematical group theory - Examples of symmetry groups in classical and quantum mechanics - Discrete groups, applications to geometry and in condensed matter theory - Group actions, representation theory - Topological groups, Lie groups and Lie algebras - Applications to quantum theory of many-particle systems
Courses and teaching forms	• Symmetry Groups in Physics (V) — 4 SWS • Exercises in Symmetry Groups in Physics (Ü) — 2 SWS
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	biennial
Literature	To be announced in the course.

Workload (partial performances and total):

	LP	P (hrs)	S (hrs)	PV (hrs)
• Lecture	6	56	62	62
• Exercises	2	28	32	-
Total workload	8	84	94	62

Module title	**Condensed-Matter Theory: Special Topics**
Module number	PHY-MV-FN-T28
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module

Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Daniela Pfannkuche/ Prof. Dr. Michael Potthoff
Lecturers	Members of the teaching staff from the Department of Physics
Language	English
Qualification objectives	Students are familiar with modern topics and have experience in using special methods of condensed matter theory.
Content	- Topological properties of selected model systems - Ballistic transport - Quantum Hall effects - Green's functions and diagrammatic perturbation theory - Magnetism
Courses and teaching forms	• Condensed-Matter Theory: Special Topics (V) 4 SWS • Exercises - Condensed-Matter Theory: Special Topics (Ü) 2 SWS
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	annually
Literature	To be announced in the course.

Workload (partial performances and total):

	LP	P (hrs)	S (hrs)	PV (hrs)
• Lecture	6	56	62	62
• Exercises	2	28	32	-
Total workload	8	84	94	62

Laserphysik und Photonik (Laser physics and photonics):

Module title	**Methoden moderner Röntgenphysik I - Spektroskopie**
Module number	PHY-MV-LP-E05
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: none
Responsible person	PD Dr. Michael Martins

<table>
<tr><td>Lecturers</td><td colspan="5">PD Dr. Michael Martins; Dr. Edgar Weckert</td></tr>
<tr><td>Language</td><td colspan="5">German or English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">Students have worked out the basics of modern X-ray physics. They know the introduction to the subject but also the applications of X-rays for the investigation of a wide variety of systems. Students have acquired a sound technical knowledge to successfully complete an experimental master thesis in the field of interaction of X-rays with matter.</td></tr>
<tr><td>Content</td><td colspan="5">This includes an introduction to the subject matter but also the applications of X-rays to study a wide variety of systems
- Interaction of X-rays with matter
Absorption, scattering, Auger effect, hard and soft X-rays
- Accelerator-based sources of X-rays
Synchrotron radiation and free electron lasers
- Experimental methods
Spectroscopy and diffraction
- X-ray optics
Optical materials, EUV lithography, Fresnel equations
- Application of X-Ray Radiation
Small quantum systems</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Methoden moderner Röntgenphysik I (V)
• Übungen zu Methoden moderner Röntgenphysik I (Ü)</td><td>4 SWS
2 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>
• Lecture
• Exercises</td><td>LP
6
2</td><td>P (hrs)
56
28</td><td>S (hrs)
62
32</td><td>PV (hrs)
62
-</td></tr>
<tr><td>Total workload</td><td>8</td><td>84</td><td>94</td><td>62</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Written or oral examination
Language of the exam: German or English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">annually</td></tr>
<tr><td>Literature</td><td colspan="5">Will be announced in the course; extensive slide script.</td></tr>
</table>

Module title	**Moderne Molekülphysik – Clusterphysik**
Module number	PHY-MV-LP-E06
Semester	Summersemester

<table>
<tr><td>Applicability, module type and assignment to the curriculum</td><td colspan="5">Physik (M.Sc.): Compulsory elective module
Physics (M.Sc.): Compulsory elective module</td></tr>
<tr><td>Prerequisites for participation</td><td colspan="5">Binding: none
Recommended: none</td></tr>
<tr><td>Responsible person</td><td colspan="5">PD Dr. Michael Martins</td></tr>
<tr><td>Lecturers</td><td colspan="5">PD Dr. Michael Martins</td></tr>
<tr><td>Language</td><td colspan="5">German or English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">Students have knowledge of the fundamentals, applications and scientific status of research on clusters, as well as the knowledge to calculate geometric and electronic structures of small clusters.
They know the subject area to the size range, which lies between atoms and solid state physics. The acquired knowledge will enable them to successfully complete an experimental master thesis in the field of very small nanostructures.
The students are able to calculate geometrical and electronic structures of small clusters, which they have been enabled to do by the exercises of the introduction to quantum chemical calculus.</td></tr>
<tr><td>Content</td><td colspan="5">- Introduction to cluster physics: What are clusters?
- Fundamentals of quantum chemical methods
- Experimental methods of cluster, molecule, and ion physics
- Bonds in clusters
Geometric, electronic, chemical, and magnetic properties of mass-selected clusters
In detail the following topics are covered
- Experimental methods of cluster physics: fabrication, detection spectroscopy
- Introduction to quantum chemistry and the calculation of clusters and molecules
- Geometric structure of clusters and structure determination
- Electronic structure of clusters - photoelectron spectroscopy, metal clusters, magnetic properties
- Chemical properties and catalysis
- Carbon clusters, fullerenes and nanotubes</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">Moderne Molekülphysik – Clusterphysik (V)
Übungen zu Moderne Molekülphysik – Clusterphysik (Ü)</td><td>4 SWS
2 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td></td><td>LP</td><td>P (hrs)</td><td>S (hrs)</td><td>PV (hrs)</td></tr>
<tr><td>Lecture
Exercises</td><td>6
2</td><td>56
28</td><td>62
32</td><td>62
-</td></tr>
</table>

	Total workload	8	84	94	62
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	Umfangreiches Folienskript				

Module title	**Einführung in die Physik der Quantengase**				
Module number	PHY-MV-LP-E09				
Semester	Wintersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: none				
Responsible person	Prof. Dr. Andreas Hemmerich				
Lecturers	Prof. Dr. Andreas Hemmerich				
Language	German or English				
Qualification objectives	Students are familiar with a central area of modern atomic physics. They know the state of the art in research and can read original Literaturee independently. Experimental observations and basic theoretical concepts are equally covered. Students are prepared for an experimental or theoretical master thesis in the field of ultracold atoms.				
Content	The lecture first discusses the cooling of atomic gases using laser light as a central method for approaching absolute temperature zero and then introduces the quantum physics of gases at absolute temperature zero. Fundamental concepts at the intersection of quantum optics, thermodynamics, and many-body quantum physics are contrasted with detailed experimental observations.				
Courses and teaching forms	• Einführung in die Physik der Quantengase (V) • Übungen zur Einführung in die Physik der Quantengase (Ü)				4 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	6 2	56 28	62 32	62 -
	Total workload	8	84	94	62

Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	annually
Literature	Laser Cooling and Trapping, H. Metcalf, P. van der Straaten, Springer Verlag (1999); Bose-Einstein Condensation in Dilute Gases, C. J. Pethick and H. Smith, Cambridge University Press (2002); Script: http://photon.physnet.uni-hamburg.de/ilp/hemmerich/teaching/

Module title	**Methoden moderner Röntgenphysik II - Struktur und Dynamik kondensierter Materie**
Module number	PHY-MV-LP-E10
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Nanowissenschaften (M.Sc.): Compulsory elective module • Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: Methoden moderner Röntgenphysik I
Responsible person	PD Dr. Michael Martins
Lecturers	PD Dr. Michael Martins
Language	German or English
Qualification objectives	Students will have in-depth knowledge of the scientific state of the art of experimental research in solid state physics using modern methods of X-ray physics, as well as in-depth experimental expertise to successfully conduct an experimental master's thesis in the field of solid state and nanostructure physics.
Content	- Coherence and its applications (interference, diffraction, speckle, coherence lengths and function, structure determination with coherent X-ray scattering) - Soft matter (polymers, colloids, nanocomposites, small-angle X-ray scattering and applications) - Glass physics (physical properties, structure determination, dyna-mics, nuclear resonant scattering) - Correlated electron systems (structural properties, phase transitions, resonant X-ray scattering, magnetic properties, magnetic scattering)

Courses and teaching forms	• Methoden moderner Röntgenphysik II (V) • Übungen zu Methoden moderner Röntgenphysik II (Ü)				4 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	6 2	56 28	62 32	62 -
	Total workload	8	84	94	62
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	To be announced in the course.				

Module title	**Ultrafast Optical Physics I**
Module number	PHY-MV-LP-E11
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Markus Drescher
Lecturers	Prof. Dr. Markus Drescher
Language	English
Qualification objectives	After successful completion of this module, students will know and understand ultrashort phenomena. In addition, they know the introduction to technologies that form the basis for modern short pulse lasers. They have the basic knowledge for the description of ultrashort optical pulses as well as their generation, manipulation, diagnostics and application in modern methods of nonlinear optics and optical spectroscopy.
Content	- Description of ultrashort optical pulses and their interaction with matter; - Generation of ultrashort pulses with lasers; - Basic principles of nonlinear optics; - Diagnostics of ultrashort optical pulses; - Ultrashort pulses in non-conventional spectral regions.

	In the assigned exercises, problems are solved together in order to consolidate the acquired knowledge by means of examples and tasks.				
Courses and teaching forms	• Ultrafast Optical Physics I (V) • Exercises in Ultrafast Optical Physics I (Ü)				2 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	3	28	32	30
	• Exercises	2	28	32	-
	Total workload	5	56	64	30
Study / Examination achievements	Type of examination: Oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	To be announced in the course.				

Module title	**Modern Molecular Physics**
Module number	PHY-MV-LP-E16
Semester	Wintersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Recommended: Quantenmechanik Einführung in die Atom-, Molekular- und Laserphysik und Quantenoptik Binding: none
Responsible person	Prof. Dr. Jochen Küpper
Lecturers	Prof. Dr. Jochen Küpper
Language	English
Qualification objectives	Students know the basic concepts of modern experiments in molecular physics. They have acquired a detailed understanding of atoms and molecules and their interaction with external fields and other particles as well as an understanding of experimental concepts in molecular physics.
Content	- Introduction to (selected) modern experiments in molecular physics. - Structure of diatomic / linear molecules - Spectroscopy of diatomic / linear molecules - Molecules in external fields - fundamentals of (adiabatic) alignment and orientation, pendulum states - molecular symmetry - polyatomic molecules

	- basis of precision spectroscopy, frequency combs - introduction to molecular dynamics				
Courses and teaching forms	• Modern Molecular Physics (V) • Exercises in Modern Molecular Physics (Ü)				2 SWS 1 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	3	28	32	30
	• Exercises	1	14	16	-
	Total workload	4	42	48	30
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	To be announced in the course.				

Module title	**Ultrafast Optical Physics II**
Module number	PHY-MV-LP-E21
Semester	Summersemester
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module
Prerequisites for participation	Binding: none Recommended: none
Responsible person	Prof. Dr. Franz Kärtner
Lecturers	Prof. Dr. Franz Kärtner
Language	English
Qualification objectives	Students will have advanced knowledge in ultrashort pulse generation, amplification, manipulation and their applications in spectroscopy, metrology and the attosecond sciences. Upon successful completion, students will be able to quantitatively model and analyze ultrashort pulse laser oscillators and amplifiers, and pulse propagation in linear and nonlinear media.
Content	- Ultrafast pulse generation - Amplification, manipulation and their applications in spectroscopy, metrology and the attosecond sciences - Ultra-short pulse laser oscillators and amplifiers - Pulse propagation in linear and nonlinear media

Courses and teaching forms	• Ultrafast Optical Physics II (V) • Exercises in Ultrafast Optical Physics II (Ü)				3 SWS 1 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	5 1	42 14	54 16	54 -
	Total workload	6	56	70	54
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	To be announced in the course.				

Module title	Light-Matter-Interactions: Atoms, Molecules & (Non) Linear Optics	
Module number	PHY-MV-LP-E22	
Semester	Summersemester	
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module	
Prerequisites for participation	Binding: none Recommended: none	
Responsible person	Prof. Dr. Christian Bressler	
Lecturers	Members of the teaching staff from the Department of Physics	
Language	English	
Qualification objectives	Students will learn about (classical) radiation lifetimes and linewidths, polarization and methods to measure these properties (spectrometers, detectors, TCSPC, etc.). We develop an understanding of various broadening mechanisms (pressure, Doppler, travel time, etc.), and the concepts will be transposed towards x-ray generation and spectroscopy.	
Content	Reminder Maxwell equations, spectrometer resolution, Bohr-model, Fourier-transformations	
Courses and teaching forms	• Light-Matter Interactions: Atoms, Molecules & (Non) Linear Optics (V) • Exercises in Light-Matter Interactions: Atoms, Molecules & (Non) Linear Optics (Ü)	2 SWS 1 SWS

Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	3 1	28 14	32 16	30 -
	Total workload	4	42	48	30
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	Demtröder: Laser Spectroscopy				

Module title	**Ultrakalte Quantengase**				
Module number	PHY-MV-LP-E26				
Semester	Wintersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: none				
Responsible person	Prof. Dr. Klaus Sengstock				
Lecturers	Members of the teaching staff from the Department of Physics				
Language	German or English				
Qualification objectives	After successful completion of the module, students will have knowledge of current research topics in the field of ultracold quantum gases. Furthermore, they will have an understanding of the underlying concepts using experimental and theoretical methods.				
Content	Hubbard models, Two-dimensional Bose gases, Artificial gauge fields, BEC-BCS transition				
Courses and teaching forms	• Ultrakalte Quantengase (V) • Übungen zu Ultrakalte Quantengase (Ü)				2 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	3 2	28 28	32 32	30 -
	Total workload	5	56	64	30

Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	annually
Literature	Many-body physics with ultracold gases; Immanuel Bloch, Jean Dalibard, Wilhelm Zwerger; Rev. Mod. Phys. 80, 885 (2008); Quantum Gas Experiments: Exploring many-body states; edited by Päivi Törmä and Klaus Sengstock; ISBN 978-1-78326-474-2 (2014).

Module title	**Nonlinear Optics**				
Module number	PHY-MV-LP-E27				
Semester	Wintersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: none				
Responsible person	Prof. Dr. Franz Xaver Kärtner				
Lecturers	Prof. Dr. Franz Xaver Kärtner				
Language	English				
Qualification objectives	Students know the most important nonlinear optical processes. They are able to simulate and design frequency conversion units, ultrafast parametric optical amplifiers and measurement techniques based on nonlinear optical processes.				
Content	Nonlinear optical concepts and symmetries, nonlinear wave equation, second harmonic generation, phase matching, quasi-phase matching, optical rectification, many-Rowe relationships, sum and difference frequency generation, optical parametric amplification, ultrafast optical parametric amplification, nonlinear third-order effects, third-harmonic generation, Kerr effect, self-phase modulation, self-focusing, stimulated Raman and Brillouin scattering, optical solitons, extreme nonlinear optics: Carrier-wave Rabiflopping, higher order harmonic generation, strong field physics in solids.				
Courses and teaching forms	• Nonlinear Optics (V) • Exercises in Nonlinear Optics (Ü)				3 SWS 1 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	5	42	54	54
	• Exercises	1	14	16	-

	Total workload	6	56	70	54
Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	annually				
Literature	Nonlinear Optics, R. W. Boyd, Academic Press 2008; The Elements of Nonlinear Optics, P. N. Butcher, Cambridge University Press, 1991.				

Module title	**Nichtklassisches Licht und die zentralen Konzepte der modernen Quantenphysik**				
Module number	PHY-MV-LP-E28				
Semester	Wintersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: Festkörperlaser, Grundkenntnisse der Quantenmechanik				
Responsible person	Prof. Dr. Roman Schnabel				
Lecturers	Prof. Dr. Roman Schnabel				
Language	German or English				
Qualification objectives	After successfully completing the module, students will be able to summarize the main scientific developments in the field of non-classical light states and will have gained a deeper understanding of quantum physics via the concept of "non-classicality".				
Content	Criteria for nonclassicality; detection and generation of Fock states, squeezed states, and Einstein-Podolsky-Rosen restricted states; and Bell's inequality, teleportation, and quantum key distribution.				
Courses and teaching forms	• Nichtklassisches Licht und die zentralen Konzepte der modernen Quantenphysik (V) • Übungen zu Nichtklassisches Licht und die zentralen Konzepte der modernen Quantenphysik (Ü)				4 SWS 2 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture • Exercises	6 2	56 28	62 32	62 -
	Total workload	8	84	94	62

Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: German or English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	annually
Literature	C. C. Gerry und P. L. Knight, Introductory Quantum Optics, University Press, Cambridge (2005); H.-A. Bachor und T. C. Ralph, A guide to experiments in quantum optics, Wiley, 2nd edition (2003).

Module title	**New Experiments with XFEL Sources**				
Module number	PHY-MV-LP-E29				
Semester	Summersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: none				
Responsible person	Prof. Dr. Christian Bressler; Prof. Dr. Michael Rübhausen				
Lecturers	Members of the teaching staff from the Department of Physics				
Language	English				
Qualification objectives	After this course, students will be able to understand the details of FEL generation, XFEL experiments and will be acquainted with the different measurement techniques. follow contemporary publications in the field and prepare own ideas for future XFEL experiments.				
Content	Major recent scientific developments in the fields of spectroscopy and scattering with intense X-rays, inclu-sive atomic physics, femtosecond molecular physics, plasma physics. Also presented are experimental tools such as X-ray lenses, femtosecond timing between 2 independent light sources, X-ray emissivity spectrometers, detectors.				
Courses and teaching forms	• New Experiments with XFEL Sources (V) • Exercises in New Experiments with XFEL Sources (Ü)				2 SWS 1 SWS
Workload (partial performances and total)		LP	P (hrs)	S (hrs)	PV (hrs)
	• Lecture	3	28	32	30
	• Exercises	1	14	16	-
	Total workload	4	42	48	30

Study / Examination achievements	Type of examination: Written or oral examination Language of the exam: English Deviations will be announced at the beginning of the event.
Duration	1 semester
Frequency of the course	annually
Literature	To be announced in the course.

Module title	**Seminar: Many-body Theory of Ultracold Atoms and Solid State Systems**				
Module number	PHY-MV-LP-T02				
Semester	Wintersemester/ Summersemester				
Applicability, module type and assignment to the curriculum	• Physik (M.Sc.): Compulsory elective module • Physics (M.Sc.): Compulsory elective module				
Prerequisites for participation	Binding: none Recommended: none				
Responsible person	Prof. Dr. Ludwig Mathey				
Lecturers	Prof. Dr. Ludwig Mathey				
Language	English				
Qualification objectives	The participants work on a topic from modern atomic physics, solid state or quantum optics, and develop the expertise of this topic, as well as the competence of giving presentations.				
Content	Development and discussion of a current research topic. This includes both conceptual questions of theoretical physics, in particular in atomic physics, solid state or quantum optics, as well as applied questions, such as from the field of quantum technology.				
Courses and teaching forms	• Seminar: Many-body Theory of Ultracold Atoms and Solid State Systems (S)				2 SWS
Workload (partial performances and total)	• Seminar	LP 3	P (hrs) 28	S (hrs) 32	PV (hrs) 30
	Total workload	3	28	32	30
Study / Examination achievements	Type of examination: Referat mit schriftlicher Ausarbeitung Language of the exam: English Deviations will be announced at the beginning of the event.				
Duration	1 semester				
Frequency of the course	every semester				
Literature	To be announced in the course.				

<table>
<tr><th>Module title</th><th colspan="5">Theory of Photon-Matter Interactions</th></tr>
<tr><td>Module number</td><td colspan="5">PHY-MV-LP-T03</td></tr>
<tr><td>Semester</td><td colspan="5">Wintersemester</td></tr>
<tr><td>Applicability, module type and assignment to the curriculum</td><td colspan="5">• Nanowissenschaften (M.Sc.): Compulsory elective module
• Physik (M.Sc.): Compulsory elective module
• Physics (M.Sc.): Compulsory elective module</td></tr>
<tr><td>Prerequisites for participation</td><td colspan="5">Binding: none
Recommended: Theoretische Physik I-III</td></tr>
<tr><td>Responsible person</td><td colspan="5">Prof. Dr. Robin Santra</td></tr>
<tr><td>Lecturers</td><td colspan="5">Prof. Dr. Robin Santra, Prof. Dr. Nina Rohringer</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Qualification objectives</td><td colspan="5">Students will be able to develop a precise quantum mechanical description for practically relevant situations of light-matter interaction. They have achieved a conceptual and quantitative understanding of experiments that focus on the behavior of electrons in the electromagnetic field. This generally includes experiments with optical lasers as well as with X-ray sources.</td></tr>
<tr><td>Content</td><td colspan="5">1. canonical formalism
2. quantum theory of the free electromagnetic field
3. quantum theory of many-electron systems
4. interaction between the photon field and the electron field
5. semiclassical theory
6. applications</td></tr>
<tr><td>Courses and teaching forms</td><td colspan="4">• Theory of Photon-Matter Interactions (V)
• Exercises in Theory of Photon-Matter Interactions (Ü)</td><td>4 SWS
2 SWS</td></tr>
<tr><td rowspan="2">Workload
(partial performances and total)</td><td>
• Lecture
• Exercises</td><td>LP
6
2</td><td>P (hrs)
56
28</td><td>S (hrs)
62
32</td><td>PV (hrs)
62
-</td></tr>
<tr><td>Total workload</td><td>8</td><td>84</td><td>94</td><td>62</td></tr>
<tr><td>Study / Examination achievements</td><td colspan="5">Type of examination: Written exam (60%) and written draft (40%)
Language of the exam: English
Deviations will be announced at the beginning of the event.</td></tr>
<tr><td>Duration</td><td colspan="5">1 semester</td></tr>
<tr><td>Frequency of the course</td><td colspan="5">biennial</td></tr>
<tr><td>Literature</td><td colspan="5">• Molecular Quantum Electrodynamics, by D. P. Craig and T. Thirunamachandran, Dover
• Quantum Theory of Light, by R. Loudon, Oxford University Press</td></tr>
</table>

	• Modern Quantum Chemistry, by A. Szabo and N. S. Ostlund, Dover • Quantum Theory of Many-Particle Systems, by A. L. Fetter and J. D. Walecka, Dover • Atomic Structure Theory, by W. R. Johnson, Springer • In addition, a script will be provided.