Modules and Courses

Excellence Track

13. April 2021

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1 List of Modules and Courses

1.1 Overview of the Modules

Module	**SWS**	**CP**
soft skills		
Speak your science	4 V	3
DPG spring meetings and other conferences		3
Complementary Skills workshops of different suppliers		1
to choose		**6-9**
physics courses		
Topical Courses	3 V + 1 Ü	6
Advanced Courses	3 V + 1 Ü	6
Laboratory project	4 P	5
to choose		**14-17**
Total		**23**

1.2 List of Topical Courses

- Condensed Matter Physics
  - Selected Topics in Condensed Matter Physics
  - Modern Experimental Methods in Condensed Matter Physics
  - Materials Science
  - Introduction to Advanced Materials - from soft matter to hard matter
  - Quantum Spintronics
  - Superconductivity
  - Nonequilibrium phenomena in quantum matter
  - Introduction to Condensed Matter Theory
  - Selected Chapters of Condensed Matter Theory
  - Theory of Soft Matter I
  - Modern Computational Techniques in Condensed/Soft Matter Physics
  - Computer Simulations in Statistical Physics
  - Soft Materials at Interfaces
  - Biophysics
  - Advanced theoretical solid state physics
- Quantum, Atomic and Neutron Physics
  - Quantum Optics (Q-Ex-1)
  - Photonics (Q-Ex-2)
  - Quantum Information (Q-Ex-3)
  - Precision Fundamental Physics (Q-Ex-4)
- Nuclear and Particle Physics
  - Statistics, Data Analysis and Simulation
  - Particle Detectors
  - Accelerator Physics
  - Particle Physics
  - Astroparticle Physics
  - Cosmology and General Relativity
  - Symmetries in Physics
  - Modern Methods in Theoretical High Energy, Particle and Nuclear Physics
  - Theoretical Particle Physics
  - Theoretical Nuclear Physics
  - Introduction to Lattice Gauge Theory
  - Introduction to String Theory
  - Effective Field Theories
  - Theoretical Astroparticle Physics
  - Amplitudes and Precision Physics at the LHC
  - Functional Methods and Exact Renormalization Group

1.3 List of Advanced Courses

- Condensed Matter Physics
  - Theory of Soft Matter II
- Nuclear and Particle Physics
  - Advanced Particle Physics
  - Advanced Chapters on Subatomic Physics
  - Advanced Astroparticle- and Astrophysics
  - Advanced Accelerator Physics

2 Important Remarks

The certificate program “Excellence Track (Physics)” is aimed at high-achieving, research-oriented students. It enables them to develop their scientific knowledge and skills as well as complementary skills beyond the normal offers and requirements within the framework of their regular Master’s program at JGU. The aim is on the one hand to introduce the students to current research at an early stage and to integrate them into the working groups and on the other hand to enable the students to acquire additional scientific knowledge (Scientific Knowledge) and Complementary and Transferable Skills in a structured program. For successful participation in the Excellence Track, students enrolled for it must acquire 23 additional credit points in addition to their regular Master’s program. These must be earned before submitting the master’s thesis and are distributed across two pillars:

1. Research-related scientific competence (subject knowledge) in the field of physics with at least 14 CP. as well as

2. Complementary Skills with at least 6 CP.

All other regulations from “Modules and courses” for the M.Sc. Physics apply.

3 Detailed description of the Modules and Courses

3.1 Soft skills

Speak your science					
ID number (JOGU-StINe) 08.128.619		Workload (workload) 90 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 3 LP
1.	Courses/Teaching methods Speak your science		Contact time 4 SWS/31,5 h	Self-study 58,5 h	Credit Points 3 LP
2.	Group sizes				
3.	Qualification and program goals / Competences In this course students will learn how to present scientific results to both layman and expert audiences. After this course they will be able to organise presentation content as to make it intriguing for an audience and present science with flair and authenticity using theatre technique, thereby increasing the impact of science communication. During the course participants will work on short presentations which they will improve along the way. Regular participation to the Physics Colloquium and critical assessment of the talks via evaluation forms will provide self-reflection. Along with theatre and story, the use of slides, addressing different audiences and reacting to questions are also part of the course.				
4.	Course content Identify key messages to bring across, grab and hold the audience's attention, the art of storytelling, body-language communication, structure of a presentation, style of a presentation, getting better at reading others				
5.	Applicable to the following programs BSc Physik, MSc Physik, Excellence Track (Physics)				
6.	Recommended prerequisites				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* *8.2 Course achievements* *8.3 Module examination*				
9.	Weighting of the achievement in the overall grade 3/180 (BSc) or 6/120 (MSc)				
10.	Module frequency Every winter semester				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. C. Sfienti				
12.	Auxiliary Information				

DPG spring meetings and other conferences					
ID number (JOGU-StINe) 08.128.ET000		Workload (workload) 90 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 3 LP
1.	Courses/Teaching methods Conference		Contact time	Self-study	Credit Points 3 LP
2.	Group sizes				
3.	Qualification and program goals / Competences Current topics in physics, which forms the basis for the student's own research project as part of the master's thesis. Learning presentation techniques and testing them in front of a scientific audience. Preparation of slides and presentation in English if necessary.				
4.	Course content Student talk about the student's own research project				
5.	Applicable to the following programs Excellence Track (Physics)				
6.	Recommended prerequisites				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* *8.2 Course achievements* *8.3 Module examination* Presentation within the conference				
9.	Weighting of the achievement in the overall grade				
10.	Module frequency				
11.	Persons responsible for this module and full-time lecturers Respective organizer or research group leader				
12.	Auxiliary Information				

Complementary Skills workshops of different suppliers					
ID number (JOGU-StINe) 08.128.ET001		Workload (workload) 30 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 1 LP
1.	Courses/Teaching methods Workshop		Contact time min 14 h	Self-study	Credit Points 1 LP
2.	Group sizes				
3.	Qualification and program goals / Competences Acquisition of Complementary Skills				
4.	Course content See course descriptions of suppliers such as IMB, “General Postgraduate Program”, etc.				
5.	Applicable to the following programs Excellence Track (Physics)				
6.	Recommended prerequisites				
7.	Entry requirements Depending on the provider, registration in person via the provider’s platform or, if possible, via the MPA. The MPA Coordination Office must be notified in writing by the end of the first week of the semester if courses from the complementary skills area are to be taken. Upon successful completion of these courses, copies of the certificates of attendance must be submitted to the Coordination Office.				
8.	Mode and duration of examinations *8.1 Active participation* *8.2 Course achievements* *8.3 Module examination* If no examination is required in the course, a one-page abstract of the major course content must be submitted to the MPA Coordination Office upon successful completion of the course.				
9.	Weighting of the achievement in the overall grade				
10.	Module frequency				
11.	Persons responsible for this module and full-time lecturers Respective supplier or instructor				
12.	Auxiliary Information				

3.2 Laboratory project

Laboratory project					
ID number (JOGU-StINe) M.08.128.ET002		Workload (workload) 150 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 2	Credit Points (LP) 5 LP
1.	Courses/Teaching methods Laboratory project (P)		Contact time 4 SWS/42 h	Self-study 108 h	Credit Points 5 LP
2.	Group sizes typically 1-2 student working on the same laboratory experiment				
3.	Qualification and program goals / Competences The students are supposed to deepen advanced work in experimental and numerical-theoretical fields of physics. This is practiced by carrying out challenging experiments in two-person teams, extending over several days under supervision of experienced assistants. Usually complex data acquisition systems and computer-based analysis methods are used.				
4.	Course content An extended project in an experimental or theoretical work group has to be performed.				
5.	Applicable to the following programs Excellence Track (Physics)				
6.	Recommended prerequisites				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* *8.2 Course achievements* *8.3 Module examination* Report				
9.	Weighting of the achievement in the overall grade 5/23				
10.	Module frequency Every semester				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. W. Gradl Lecturers: All lecturers in physics				
12.	Auxiliary Information Course language: English Literature: Manuals of experiments with special references				

3.3 Topical and Advanced Courses

3.3.1 Condensed Matter Physics

Module Topical Courses: "Selected topics in Condensed Matter Physics"					
ID number (JOGU-StINe) 08.128.720		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Selected topics in Condensed Matter Physics" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences Students shall be guided towards a selection of special problems in modern Condensed Matter Physics to obtain a solid background when dealing with research related topics. Magnetism and super conductivity emerge through the correlated dynamics of electrons in solids and provide the basis of modern electronics and information technology. Surface Science is essential for an in depth understanding of miniaturized devices as well as for novel diagnostic techniques. Soft Matter shows fascinating structural and dynamic properties and nurtures a rapidly developing field of applications. Its fundamental scientific questions also related to other disciplines like biology, chemistry and medicine. By an depth treatment of one or more of these topics, the course will provide a solid basis for conducting a master thesis in the area of Condensed Matter Physics.				
4.	Course content Depending on the lecturer, the course will focus on specific topics, such as magnetism, super conductivity, heavy fermions, applied solid state physics, surface science or soft matter physics				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Knowledge of experimental physics on the level of the module Experimental Physics "Physics of Condensed Matter"				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Each summer semester				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. T. Palberg, Prof. Dr. M. Kläui Lecturers: All lecturers in experimental condensed matter physics				

Module Topical Courses: "Selected topics in Condensed Matter Physics"				
ID number (JOGU-StINe) 08.128.720	Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP

12.	Auxiliary Information Course language: English Literature: will be provided by the lecturer

Module Topical Courses: " Modern Experimental Methods in Condensed Matter Physics"					
ID number (JOGU-StINe) 08.128.721		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Modern Experimental Methods in Condensed Matter Physics" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences Students shall be guided towards both fundamental facts and special aspects of state-of-the-art experimental methods in material science. The course will therefore present important and state of the art techniques and approaches. Examples may include spectroscopic methods, scattering techniques, scanning probe techniques as well as application related characterization of novel materials, sample preparation and conditioning techniques. Dealing with one or more of such topics, the course will develop an enhanced understanding of a research related area of expertise in Condensed Matter Physics. It will further provide a solid basis for conducting a master thesis in Condensed Matter Physics in this or a related area.				
4.	Course content Depending on the lecturers, the course will focus on specific topics such as spectroscopic methods, scattering techniques, modern microscopy techniques, scanning probe techniques, synthesis strategies, sample preparation techniques or methods for material characterization under application related conditions.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Knowledge of Experimental Physics on the level of the Modul Experimentalphysik "Physik kondensierter Materie"				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Every winter semester				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. T. Palberg, Prof. Dr. M. Kläui Lecturers: All lecturers in experimental condensed matter physics				

Module Topical Courses: " Modern Experimental Methods in Condensed Matter Physics"				
ID number (JOGU-StINe) 08.128.721	Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP

12.	Auxiliary Information Course language: English Literature:

Module Topical Courses: " Materials Science"					
ID number (JOGU-StINe) 08.128.722		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Materials Science" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences Students shall be guided towards the essential physics of Material Science that is necessary for an understanding of processes in novel materials on the atomic and the nano-scale. Topics of interest covered by the course are, for example, the structure and properties of functional materials, nanomaterials, fluids and soft materials, glasses, functionalized surfaces, formation of and transitions within solids, modern methods of material science, as well as concepts and fundamentals of novel materials including their development and application. Dealing with one or more of such topics, the course will develop an enhanced understanding of a research related area of expertise in Condensed Matter Physics. It will further provide a solid basis for conducting a master thesis in Condensed Matter Physics in this or a related area.				
4.	Course content Depending on the lecturer, the course will focus on specific topics like e.g. functional materials, nano materials, soft matter materials, glasses, functionalized sufaces, development strategies, characterization methods, phase transitions or materials for specific applications				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Knowledge of Experimental Physics on the level of the Modul Experimentalphysik "Physik kondensierter Materie"				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Every semester				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. T. Palberg, Prof. Dr. M. Kläui Lecturers: All lecturers in experimental condensed matter physics				
12.	Auxiliary Information Course language: English Literature:				

Modul Spezialvorlesung I und II: „Introduction to Advanced Materials - from soft matter to hard matter“					
ID number (JOGU-StINe) 08.128.7012		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Vorlesung mit Übung „Introduction to Advanced Materials - from soft matter to hard matter“ (WP) Vorlesung (WP) Übung (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Vorlesung: unbegrenzt Übungen: 20				
3.	Qualification and program goals / Competences Den Studierenden sollen die Grundlagen der Physik und Chemie harter und weicher Materie nahe gebracht werden. Insbesondere soll ein Verständnis darüber erzielt werden, wie die Größe, die nanoskopische Anordnung sowie die Wechselwirkungsenergie der atomaren, molekularen und makromolekularen bzw. kolloidalen Bausteine die Materialeigenschaften bestimmt. Als universelle Analysemethode wird Streuung eingeführt, was sich sowohl zur Untersuchung von harter, als auch von weicher Materie eignet. Für die weiche Materie erfolgt überdies eine Einführung in die Rheologie. An einem oder an mehreren speziellen Themen soll ein vertieftes Verständnis für ein forschungsnahes Spezialgebiet der kondensierten Materie entstehen, das eine gute Grundlage darstellt, eine Masterarbeit erfolgreich durchführen zu können.				
4.	Course content • Einführung in Kristallstrukturen, Gitterschwingungen und Gitterdefekte • Einführung in weiche Materie inklusive Polymere • Einführung in Streuung mit Photonen, Neutronen und Elektronen zur Untersuchung von Kristallen, Polymeren und magnetischen Systemen • Einführung in die Rheologie von Polymeren • Einführung in den Magnetismus				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Kenntnisse auf dem Niveau des Moduls Experimentalphysik „Physik kondensierter Materie“				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* Vorab Bearbeitung der online bereitgestellten e-Learning Materialien, insbes. der Fragen darin. *8.2 Course achievements* *8.3 Module examination* Gemeinsame mündliche Prüfung (30-45 Min.) über beide Spezialvorlesungen				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency In der Regel jährlich				

Modul Spezialvorlesung I und II: „Introduction to Advanced Materials - from soft matter to hard matter“				
ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.7012	180 h	1	1	6 LP

11.	Persons responsible for this module and full-time lecturers Modulbeauftragte: Prof. Dr. M. Kläui Lehrende: Dozenten und Dozentinnen aus dem Bereich der experimentellen kondensierten Materie und der Chemie
12.	Auxiliary Information Sprache: Englisch Literatur: C. Kittel: Einführung in die Festkörperphysik, R. Gross: Festkörperphysik, R. A. J. Jones: Soft Condensed Matter, M. Rubinstein & R. H. Colby: Polymer Physics; S. Blundell: Magnetism in Condensed Matter

<table>
<tr><th colspan="6">Modul Spezialvorlesung I und II: „Quantum Spintronics“</th></tr>
<tr><td colspan="2">ID number
(JOGU-StINe)
08.128.7014</td><td>Workload
(workload)
180 h</td><td>Course Duration
(laut Studienverlaufsplan)
1</td><td>Designated term
(laut Studienverlaufsplan)
1</td><td>Credit Points
(LP)
6 LP</td></tr>
<tr><td>1.</td><td colspan="2">Courses/Teaching methods
Vorlesung mit Übung „Quantum Spintronics“ (WP)
Vorlesung (WP)
Übung (WP)</td><td>Contact time

3 SWS/31.5 h
1 SWS/10.5 h</td><td>Self-study
138 h</td><td>Credit Points
6 LP</td></tr>
<tr><td>2.</td><td colspan="5">Group sizes
Vorlesung: unbegrenzt
Übungen: 20</td></tr>
<tr><td>3.</td><td colspan="5">Qualification and program goals / Competences
Den Studierenden sollen die physikalischen Grundlagen des Magnetismus von klassischen makroskopischen Beschreibungen bis zum quantenmechanischen Einzelspin nahe gebracht werden. Insbesondere soll ein Verständnis erzielt werden, wie einzelne Elektronen im Festkörper durch die Austauschkopplung zu einer makroskopischen Magnetisierung führen. Die Dynamik von Spins wird klassisch als auch quantenmechanisch besprochen und Methoden zur Messung werden erklärt. Auf der Anwendungsseite wird energiesparende Magnetoelektronik für Speicher, Sensorik und Logik eingeführt und Spin-basierte Qubits werden erklärt. Studenten werden die Konzepte von emergenten Phänomenen und den Übergang von klassischen und quantenmechanischen Effekten im Beispiel des Spin verstehen und das Anwendungspotential abschätzen können. An einem oder an mehreren speziellen Themen soll ein vertieftes Verständnis für ein forschungsnahes Spezialgebiet der kondensierten Materie entstehen, das eine gute Grundlage darstellt, eine Masterarbeit erfolgreich durchführen zu können.</td></tr>
<tr><td>4.</td><td colspan="5">Course content
Einzel-Spins und resultierende magnetische Momente, Spin Ensembles und thermodynamische Effekte, Kopplung von Spins, Spindynamik, Mikromagnetismus, Spin Torque Effekte, Spin Transport und Magnetowiderstandseffekte, Realisierung von QuBits mit Spins, Messmethoden für Spins, Anwendungen von Spin.</td></tr>
<tr><td>5.</td><td colspan="5">Applicable to the following programs
MSc. Physics</td></tr>
<tr><td>6.</td><td colspan="5">Recommended prerequisites
Kenntnisse auf dem Niveau des Moduls Experimentalphysik „Physik kondensierter Materie“</td></tr>
<tr><td>7.</td><td colspan="5">Entry requirements</td></tr>
<tr><td>8.</td><td colspan="5">Mode and duration of examinations
8.1 Active participation
Erfolgreiches Bearbeiten der Übungsaufgaben
8.2 Course achievements

8.3 Module examination
Gemeinsame mündliche Prüfung (30-45 Min.) über beide Spezialvorlesungen</td></tr>
<tr><td>9.</td><td colspan="5">Weighting of the achievement in the overall grade
6/120</td></tr>
<tr><td>10.</td><td colspan="5">Module frequency
In der Regel jährlich</td></tr>
<tr><td>11.</td><td colspan="5">Persons responsible for this module and full-time lecturers
Modulbeauftragte: Prof. Dr. M. Kläui
Lehrende: Dozenten und Dozentinnen aus dem Bereich der experimentellen kondensierten Materie</td></tr>
</table>

Modul Spezialvorlesung I und II: „Quantum Spintronics“				
ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.7014	180 h	1	1	6 LP

12.	Auxiliary Information Sprache: Englisch Literatur: Speziellere Lehrbücher der kondensierten Materie, Lehrbücher zu Magnetismus, S. Blundell: Magnetism in Condensed Matter, J. M. D. Coey: Magnetism and Magnetic Materials, J. Stöhr & H. c. Siegmann: Magnetism – from fundamentals to nanoscale dynamics, speziellen Materialien, Sommerschulprogramme, Forschungsnahe Veröffentlichungen

Module Topical Courses: "Superconductivity"					
ID number (JOGU-StINe) 08.128.7013		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Superconductivity" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The students should get acquainted with the physical foundations of superconductivity. In particular they should understand how the independent individual electrons in a solid condense into a macroscopic quantum state, what is the symmetry of the order parameter, and how the order parameter is determined. An understanding of the transport properties of the superconducting ground state shall be achieved with respect to the possibilities of dissipation free transport and the realization of superconducting quantum phenomena as ultrasensitive sensors or qubits. In one or several special topics a deeper understanding of a subfield of current research in solid state physics shall be achieved forming the foundation to successfully prepare a master thesis on these topics.				
4.	Course content Electrons in solids, BCS-theory for Cooper pair formation and condensation in the ground state, phase transition and transport properties Ginzburg-Landau description, type I and type II superconductors, the Josephson effect and its applications in ultra sensitive sensors and as voltage normal, critical currents in superconductors, superconducting magnets, superconducting qubits, high temperature superconductivity, transport in two-dimensional systems, related quantum effects as Quantum Hall effect.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Knowledge at the level of the module in experimental physics: "Physics of condensed matter"				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Generally every year				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. G. Jakob, Prof. Dr. M. Jourdan Lecturers: All lecturers in experimental condensed matter physics				

Module Topical Courses: "Superconductivity"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.7013	180 h	1	1	6 LP

12.	Auxiliary Information Course language: English Literature: Specialized textbooks of condensed mmatter physics, textbooks of superconductivity, Tinkham: Introduction to Superconductivity; Kleiner+Buckel: Superconductivity, specialized materials, summer school lectures, research papers

Module Topical Courses: "Nonequilibrium phenomena in quantum matter"					
ID number (JOGU-StINe) 08.128.752		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Nonequilibrium phenomena in quantum matter" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences This lecture addresses non-equilibrium phenomena in advanced solids, with focus on systems exhibiting low temperature macroscopic quantum states like superconductivity, charge/spin density waves, ferro- and anti-ferromagnetism. These states can be studied and manipulated by femtosecond optical pulses using the so-called "pump-probe" approach. Femtosecond technology and spectroscopy have experienced major developments in the recent two decades, providing means to femtosecond switching of magnetization, observations of Higgs modes in superconductors and light-induced enhancement of superconductivity, or making molecular movies, just to mention a few. After introducing the general principle of the "pump-probe" spectroscopy, we will address several case studies, where different experimental techniques (THz spectroscopy, ultrafast electron diffraction, time-resolved ARPES, etc.) will be applied to study one of the above-mentioned macroscopic quantum states. This way we will learn the basics of non-linear optics, the novel laser-based techniques (used both in the lab and at large-scale facilities) and address physics of different material classes with fascinating functional properties. The course should provide a broad overview of techniques and nonequilibrium phenomena in correlated solids, and thus present solid grounds for MSc work in several areas of research in solid state physics.				
4.	Course content Basics of nonlinear optics & ultrafast lasers; Principles of femtosecond real-time spectroscopy and modulation techniques; Femtosecond thermo-modulation in metals; Terahertz generation and THz time-domain spectroscopy; Basics of superconductivity; Electrodynamics of systems with broken symmetry ground states; Dynamics of the superconducting gap; Microwave enhancement of superconductivity; Collective (Higgs) modes in superconductors; Basics of Charge and Spin density waves; Time-resolved photoelectron spectroscopy; Femtosecond X-ray and electron diffraction – making molecular movies; Magnetization dynamics and switching				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Knowledge at the level of the module in experimental physics: "Physics of condensed matter"				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				

Module Topical Courses: "Nonequilibrium phenomena in quantum matter"				
ID number (JOGU-StINe) 08.128.752	Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP

9.	Weighting of the achievement in the overall grade 6/120
10.	Module frequency Normally every third semester
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. J. Demsar Lecturers: All lecturers in experimental condensed matter physics
12.	Auxiliary Information Course language: English Literature: B.E.A. Saleh, M.C. Teich: Fundamentals of Photonics, Wiley, 1991; Kittel: Introduction to Solid State physics; M. Dressel and G. Grüner: Electrodynamics of Solids; S. Blundell: "Magnetism in Condensed Matter"; Oxford Master Series in Physics; M. Tinkham: Introduction to Superconductivity; G. Grüner: Density waves in solids; selected scientific publications & reviews

Module Topical Courses: "Introduction to Condensed Matter Theory"					
ID number (JOGU-StINe) 08.128.723		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Introduction to Condensed Matter Theory" (WP) Lecture (WP) Excercises (WP)	Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP	
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences Building on the introductory courses on quantum mechanics and statistical thermodynamics, the central concepts of the description of crystalline solids shall be discussed. Starting from lattice periodicity and crystal symmetry, concepts like the electronic structure (electrons in a crystal field potential) and elementary excitations (phonons, magnons, plasmons, etc.) and their consequences for the various physical properties of solids at low temperatures are explained, thereby creating a solid basis to deal with research-related topics in the field of condensed matter theory.				
4.	Course content Crystal structure, symmetry, the concept "reciprocal lattice", lattice dynamics in the harmonic approximation, relation to the elastic constants, electrons in a crystal field (Bloch wave and Wannier functions, energy bands, etc.), basic concepts of magnetism, magnons, etc. Also, depending on the choice of the lecturer, selected advanced topics (e.g., scattering theory of solids, electron-phonon interaction, plasmons and dielectric response, etc.) are presented.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Knowledge at the level of the courses Theoretical Physics 1-5 of the Bachelor's degree program				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Every summer semester				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. P. van Dongen Lecturers: All lecturers in theoretical "hard" condensed matter physics				
12.	Auxiliary Information Course language: English Literature:				

<table>
<tr><th colspan="6">Module Topical Courses: “Selected Chapters of Condensed Matter Theory”</th></tr>
<tr><td colspan="2">ID number
(JOGU-StINe)
08.128.724</td><td>Workload
(workload)
180 h</td><td>Course Duration
(laut Studienverlaufsplan)
1</td><td>Designated term
(laut Studienverlaufsplan)
1</td><td>Credit Points
(LP)
6 LP</td></tr>
<tr><td>1.</td><td colspan="2">Courses/Teaching methods
Lecture with excercises “Selected Chapters of Condensed Matter Theory” (WP)
Lecture (WP)
Excercises (WP)</td><td>Contact time

3 SWS/31.5 h
1 SWS/10.5 h</td><td>Self-study
138 h</td><td>Credit Points
6 LP</td></tr>
<tr><td>2.</td><td colspan="5">Group sizes
Lecture: unlimited
Excercises: 20</td></tr>
<tr><td>3.</td><td colspan="5">Qualification and program goals / Competences
Building on the foundations of statistical thermodynamics and/or quantum mechanics of many-body systems, the students will be introduced to specific aspects of the theory of quantum many-particle systems ("hard"condensed matter). Topics to be treated may include the theory of correlated fermions, modern static and dynamic phenomena of magnetism, low-dimensional systems, disorder, quantum phase transitions, many-body theory and their numerical methods, the theory of superfluidity and superconductivity, and topological quantum matter. Having completed this course, the student should have achieved a deeper understanding and a research-level specialization of condensed matter theory, which should form a solid foundation to successfully complete a master’s thesis in a related field of physics.</td></tr>
<tr><td>4.</td><td colspan="5">Course content
Depending on the lecturer, the lecture may be focused on numerical methods in many-body physics, the theory of correlated fermions, the theory of superconductivity, modern magnetism, or topological systems.</td></tr>
<tr><td>5.</td><td colspan="5">Applicable to the following programs
MSc. Physics</td></tr>
<tr><td>6.</td><td colspan="5">Recommended prerequisites
Knowledge at the level of the courses Theoretical Physics 1-5 of the Bachelor’s degree program</td></tr>
<tr><td>7.</td><td colspan="5">Entry requirements</td></tr>
<tr><td>8.</td><td colspan="5">Mode and duration of examinations
8.1 Active participation
successful completion of the exercises
8.2 Course achievements

8.3 Module examination
Common oral examination (30 – 45 Min.) covering two topical courses</td></tr>
<tr><td>9.</td><td colspan="5">Weighting of the achievement in the overall grade
6/120</td></tr>
<tr><td>10.</td><td colspan="5">Module frequency
Every summer semester</td></tr>
<tr><td>11.</td><td colspan="5">Persons responsible for this module and full-time lecturers
Responsible: Prof. Dr. P. van Dongen
Lecturers: All lecturers in theoretical “hard” condensed matter physics</td></tr>
</table>

Module Topical Courses: "Selected Chapters of Condensed Matter Theory"				
ID number (JOGU-StINe) 08.128.724	Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP

12\. Auxiliary Information

Course language: English

Literature:

- J. P. Hansen, I. R. McDonald, Theory of Simple Liquids, Academic Press, London 2006;
- J. Yeomans, Statistical Mechanics of Phase Transitions, Clarendon Press, Oxford, 1992;
- A. Onuki, Phase Transition Dynamics, Cambridge University Press, Cambridge, 2002;
- K. Binder, W. Kob, Glassy Materials and Disordered Solids. An Introduction to Their Statistical Mechanics, World Scientific, Singapore, 2005;
- W. Paul, J. Baschnagel, Stochastic Processes, From Physics to Finance, Springer, Berlin, 2000;
- A. Auerbach, Interacting Electrons and Quantum Magnetism, Springer (1994);
- P. Fulde, Electron Correlations in Molecules and Solids, Springer (1995);
- L. Kantorovich, Quantum Theory of the Solid State: An Introduction, Kluwer (2004);
- D.C. Mattis, The Theory of Magnetism Made Simple: An Introduction to Physical Concepts and to Some Useful Mathematical Methods, World Scientific, 2006;

Module Topical Courses: "Theory of Soft Matter I"					
ID number (JOGU-StINe) 08.128.725		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Theory of Soft Matter I" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The students become acquainted with the statistical description of systems with large fluctuations for the example of various soft matter systems. A special focus lies on general principles that may be applied for different material classes.				
4.	Course content General concepts: Modeling, symmetry, and conservation laws, scattering laws, self similarity and scale invariance, mean-field approaches and Landau theories, Brownian dynamics, Critical dynamics; Structure: Polymers (random walk, self-avoiding walk, blob concept, Flory screening, Flory Huggins theory, Path integral description of polymers, polymer field theory), Membranes (fluid, hexatic and crystalline membranes), Landau-de Gennes theory of liquid crystals; Dynamics: Polymers (Rouse model), hydrodynamics at low Reynolds numbers, and (possibly) active and nonequilibrium matter.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Theory 1-4, in particular Statistical Physics				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Upon request				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. K. Kremer, Prof. Dr. F. Schmid Lecturers: All lecturers in theoretical condensed matter physics				

Module Topical Courses: "Theory of Soft Matter I"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.725	180 h	1	1	6 LP

12.	Auxiliary Information Course language: English Literature: • de Gennes, Scaling Concepts in Polymer Physics • Doi/Edwards, The Theory of Polymer Dynamics • Grosberg/Khokhlov, Statistical Mechanics of Macromolecules • Chaikin/Lubensky, Principles of Condensed Matter Physics • Russel/Saville/Schowalter, Colloidal Dispersions • Dhont: An introduction to the dynamics of colloids

Module Topical Courses: "Modern Computational Techniques in Condensed/Soft Matter Physics"					
ID number (JOGU-StINe) 08.128.745		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Modern Computational Techniques in Condensed/Soft Matter Physics" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences Students attending the course will learn the use of advanced tools and techniques for efficiently performing computer simulations in the field of condensed and soft matter physics, possibly including molecular biophysics. These techniques will enable them to study phenomena like phase transitions in a variety of systems (liquids, solids, polymer melts etc.), conformational changes, chemical reactions, non-equilibrium or driven phenomena etc.				
4.	Course content The topics of the course will be selected according to the docent and can include free energy calculations, enhanced sampling techniques, simulation of rare events, critical phenomena, non-equilibrium dynamics, coarse-graining, density functional theory, force-field optimization, polarizable force fields, long range interactions, etc.				
5.	Applicable to the following programs MSc. Physics, Master "Computational Sciences" with focus on physics				
6.	Recommended prerequisites				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency At least once per year				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. F. Schmid Lecturers: All lecturers in condensed matter theory				
12.	Auxiliary Information Course language: English Literature: To be announced in class				

Module Topical Courses: “Computer Simulations in Statistical Physics”					
ID number (JOGU-StINe) 08.128.801		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises “Computer Simulations in Statistical Physics” (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences Students will learn to describe complex physical problems in terms of simple models, to translate these into algorithms, and to implement the algorithms correctly and in an efficient way on modern computer architectures. They will learn to appreciate the importance of computer simulations in their interaction with theory and experiment.				
4.	Course content Molecular dynamics simulations, symplectic integrators, Markov chain Monte Carlos, random number generators, analysis of time series, finite size effects and simulations in different thermodynamic ensembles.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Every winter semester				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. F. Schmid Lecturers:Lecturers in theoretical condensed matter physics				

Module Topical Courses: "Computer Simulations in Statistical Physics"				
ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.801	180 h	1	1	6 LP

12. Auxiliary Information

Course language: English

Literature:

- D. Frenkel, B. Smit, Understanding Molecular Simulation – From Algorithms to Applications, Academic Press, San Diego, 2002
- D. P. Landau, K. Binder, A Guide to Monte Carlo Simulations in Statistical Physics, Cambridge University Press, New York, 2005
- M. P. Allen, D. J. Tildesley, Computer Simulations of Liquids, Clarendon Press, Oxford, 1987
- J. M. Haile, Molecular Dynamics Simulations – Elementary Methods, Wiley, New York, 1997.

Module Topical Courses: “Soft Materials at Interfaces”

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.7010	180 h	1	1	6 LP

	Courses/Teaching methods	Contact time	Self-study	Credit Points
1.	Lecture with excercises “Soft Materials at Interfaces” (WP) Lecture (WP) Excercises (WP)	 3 SWS/31.5 h 1 SWS/10.5 h	138 h	6 LP

2. Group sizes

Lecture: unlimited
Excercises: 20

3. Qualification and program goals / Competences

The course gives an introduction to the physical principles to understand the structure and dynamics of soft condensed matter adjacent to solid, liquid, and vapor interfaces. Soft matter interfaces are ubiquitous in life and technology, see for example, OLED displays on smartphones, soap bubbles, many biological tissues.

Particular emphasis is given to the links connecting intermolecular forces with molecular scale structure and physical materials properties. The course further introduces the experimental techniques required to study soft matter interfaces on the relevant time and length scales. Focus is set to scattering and scanning probe techniques, providing complementary information in real and reciprocal space.

The course will enable the students to understand numerous physical phenomena surrounding us in everyday live while also providing them with the basic knowledge for improving the performance of modern soft materials for specific applications. Examples help to develop a deeper understanding and to explore links to other branches of physics.

4. Course content

Topics may vary depending on the preferences of the lecturers. Typical topics are

- Thermodynamics of interfaces
- Surface tension
- Self-organization of soft matter thin films
- Charged solid/liquid interfaces and Helmholtz double layer
- Interfacial forces and colloidal stability
- Interface induced phase transitions
- Adsorption and wetting
- Surfactants and Emulsions
- Interfacial freezing and premelting
- Liquids in nanoporous materials
- X-ray scattering and spectroscopy
- Scanning probe techniques and force measurements

5. Applicable to the following programs

MSc. Physics

6. Recommended prerequisites

7. Entry requirements

Module Topical Courses: "Soft Materials at Interfaces"				
ID number (JOGU-StINe) 08.128.7010	Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP

8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses
9.	Weighting of the achievement in the overall grade 6/120
10.	Module frequency Annually
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. Hans-Jürgen Butt, Prof. Dr. Thomas Palberg, Prof. Dr. F. Schmid Lecturers: All lecturers in condensed matter physics
12.	Auxiliary Information Course language: English Literature: • Metin Tolan, "X-Ray Scattering from Soft-Matter Thin Films", Springer (1999). • Jens Als-Nielsen, Des McMorrow, "Elements of Modern X-ray Physics", 2nd Edition, Wiley (2011). • Peter S. Pershan , Mark Schlossman, "Liquid Surfaces and Interfaces : Synchrotron X-ray Methods", Cambridge University Press (2012). • Hans-Jürgen Butt, Karlheinz Graf, Michael Kappl, "Physics and Chemistry of Interfaces", 3rd Edition, Wiley (2013).

<table>
<tr><td colspan="6">Module Topical Courses: “Biophysics”</td></tr>
<tr><td colspan="2">ID number
(JOGU-StINe)
08.128.753</td><td>Workload
(workload)
180 h</td><td>Course Duration
(laut Studienverlaufsplan)
1</td><td>Designated term
(laut Studienverlaufsplan)
1</td><td>Credit Points
(LP)
6 LP</td></tr>
<tr><td>1.</td><td colspan="2">Courses/Teaching methods
Lecture with excercises “Biophysics” (WP)
Lecture (WP)
Excercises (WP)</td><td>Contact time

3 SWS/31.5 h
1 SWS/10.5 h</td><td>Self-study
138 h</td><td>Credit Points
6 LP</td></tr>
<tr><td>2.</td><td colspan="5">Group sizes
Lecture: unlimited
Excercises: 20</td></tr>
<tr><td>3.</td><td colspan="5">Qualification and program goals / Competences
The course gives an introduction to phenomena in biological matter using concepts from theoretical physics in order to expose and understand common physical principles. Students will learn about the elementary molecular components of a cell, as well as the interactions of these components and the formation of hierarchical functional structures. The course will enable students to understand and approach phenomena in biological systems from a physics perspective. Particular attention is given to the application of established concepts from soft matter physics and their application to living matter.</td></tr>
<tr><td>4.</td><td colspan="5">Course content
There will be an introduction to living matter (tissue, bacteria, cells, etc.) and its organization, as well as the molecular players (proteins, polymers, enzymes). Further topics may vary depending on the preferences of the lecturers. Typical topics include:
• Stochastic dynamics, diffusion, and single molecule dynamics
• Basics of non-equilibrium thermodynamics and information theory
• Physical limits to sensing
• Biochemical networks and criticality
• Mechanochemical coupling, molecular motors and force generation
• Collective behavior and phase behavior
• Self-organization and structure formation
• X-ray scattering and the structure of proteins
• Membranes and their theoretical description</td></tr>
<tr><td>5.</td><td colspan="5">Applicable to the following programs
MSc. Physics</td></tr>
<tr><td>6.</td><td colspan="5">Recommended prerequisites
A working knowledge of statistical physics (Theoretical Physics 4) is recommended</td></tr>
<tr><td>7.</td><td colspan="5">Entry requirements</td></tr>
<tr><td>8.</td><td colspan="5">Mode and duration of examinations
8.1 Active participation
successful completion of the exercises
8.2 Course achievements

8.3 Module examination
Common oral examination (30 – 45 Min.) covering two topical courses</td></tr>
<tr><td>9.</td><td colspan="5">Weighting of the achievement in the overall grade
6/120</td></tr>
<tr><td>10.</td><td colspan="5">Module frequency
irregular</td></tr>
</table>

Module Topical Courses: "Biophysics"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.753	180 h	1	1	6 LP

11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. Thomas Speck, Prof. Dr. Friederike Schmid Lecturers: All lecturers in condensed matter physics
12.	Auxiliary Information Course language: English Literature: • William Bialek, Biophysics: Searching for Principles, Princeton University Press (2013).

Module Topical Courses: "Advanced theoretical solid state physics"					
ID number (JOGU-StINe) 08.128.754		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Advanced theoretical solid state physics" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences Students shall get acquainted with basic and advanced concepts and methods of theoretical solid state physics. They will learn fundamentals concepts of electronic structure theory that explain the stability of matter, of symmetries that govern many structural properties of matter, of transport mechanisms, and of the role of excitations and defects for many material properties in solid matter. The class will provide basic knowledge to prepare them for more advanced classes in solid state theory and for conducting a master thesis in Condensed Matter Theory or Experiment.				
4.	Course content Crystal symmetries, Reciprocal lattice, Phonons, Electron gas, Band structure, Methods for calculating Band Structure, Fermi surface, Conductors and Semiconductors, Quasiparticles concepts, Defects and Disordered systems, Transport, Optical properties, Magnetism, Superconductivity				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Quantum mechanics, Statistical Physics Knowledge of condensed matter at the level of the class "Physics of condensed matter"				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Each summer semester				
11.	Persons responsible for this module and full-time lecturers Module responsible: Prof. Dr. J. Sinova Lecturers:Lecturers in theoretical solid state physics				

Module Topical Courses: "Advanced theoretical solid state physics"					
ID number (JOGU-StINe) 08.128.754		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
12.	Auxiliary Information Course language: English Literature: • Ashcroft, Mermin: Solid State Physics, Saunders College • Kittel: Quantum Theory of Solids, Wiley • Jones, March, Theoretical Solid State Physics, Vol 1,2, John Wiley • Ziman, Principles of the Theory of Solids, Cambridge University Press				

Module Advanced Course: “Theory of Soft Matter II”					
ID number (JOGU-StINe) 08.128.800		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 2	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises “Theory of Soft Matter II” (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The students get acquainted with the statistical description of systems with large fluctuations, given the example of different soft matter systems. Special focus lies on general principles which can be applied for different material classes.				
4.	Course content Topics are selected depending on the preferences of the lecturers. Possible topics are: DLVO theory, hydrodynamic interactions in colloids and polymers, micro swimmers and active particles, Zimm model, reptation model, networks and rubber elasticity, structure of polyelectrolytes, viscoelasticity, materials science aspects of soft matter systems, statistical physics of interfaces, wetting, capillary waves.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Theory 1-5, in particular Statistical Physics				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Written exam (90-180 Min.) or oral examination (30 Min.)				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. Kurt Kremer, Prof. Dr. F. Schmid Lecturers: All lecturers in theoretical condensed matter physics				

Module Advanced Course: "Theory of Soft Matter II"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.800	180 h	1	2	6 LP

12.	Auxiliary Information Course language: English Literature: • de Gennes, Scaling Concepts in Polymer Physics • Doi/Edwards, The Theory of Polymer Dynamics • Grosberg/Khokhlov, Statistical Mechanics of Macromolecules • Chaikin/Lubensky, Principles of Condensed Matter Physics • Russel/Saville/Schowalter, Colloidal Dispersions. • Dhont: An Introduction to Dynamics of Colloids

3.3.2 Quantum, Atomic and Neutron Physics

<table>
<tr><th colspan="6">Module Topical Courses: “Quantum Optics (Q-Ex-1)”</th></tr>
<tr><td colspan="2">ID number
(JOGU-StINe)
08.128.729</td><td>Workload
(workload)
180 h</td><td>Course Duration
(laut Studienverlaufsplan)
1</td><td>Designated term
(laut Studienverlaufsplan)
1</td><td>Credit Points
(LP)
6 LP</td></tr>
<tr><td>1.</td><td colspan="2">Courses/Teaching methods
Lecture with excercises “Quantum Optics” (WP), frequently joint theoretical-experimental course
Lecture (WP)
Excercises (WP)</td><td>Contact time

3 SWS/31.5 h
1 SWS/10.5 h</td><td>Self-study
138 h</td><td>Credit Points
6 LP</td></tr>
<tr><td>2.</td><td colspan="5">Group sizes
Lecture: unlimited
Excercises: 20</td></tr>
<tr><td>3.</td><td colspan="5">Qualification and program goals / Competences
The students shall be introduced to the principles of the quantized description of radiation fields. Theoretical methods shall be discussed along with selected experiments which demonstrate effects of quantized radiation fields.</td></tr>
<tr><td>4.</td><td colspan="5">Course content
Basic entry course to experimental quantum optics. Interdisciplinary experiment-theory course, frequently lectured jointly by experimentalists and theorists.
Contents:
• Quantization of electromagnetic fields, quantum states of radiation fields
• correlations in the radiation field and in photon statistics
• quantized interaction of atoms with light, Jaynes-Cummings Hamiltonian
• “dressed states”
Further possible topics:
• Photon detectors
• single photon sources and entangled photons
• Bell equations, quantum mechanical correlations of entangled photon pairs
• cavity quantum electrodynamics</td></tr>
<tr><td>5.</td><td colspan="5">Applicable to the following programs
MSc. Physics</td></tr>
<tr><td>6.</td><td colspan="5">Recommended prerequisites
Experimental Physics 5a “Atomic and Quantum Physics”, Theoretical Physics 3 “Quantum Mechanics”</td></tr>
<tr><td>7.</td><td colspan="5">Entry requirements</td></tr>
<tr><td>8.</td><td colspan="5">Mode and duration of examinations
8.1 Active participation
successful completion of the exercises
8.2 Course achievements

8.3 Module examination
Common oral examination (30 – 45 Min.) covering two topical courses</td></tr>
<tr><td>9.</td><td colspan="5">Weighting of the achievement in the overall grade
6/120</td></tr>
</table>

<table>
<tr><th colspan="6">Module Topical Courses: “Quantum Optics (Q-Ex-1)”</th></tr>
<tr><td colspan="2">ID number
(JOGU-StINe)
08.128.729</td><td>Workload
(workload)
180 h</td><td>Course Duration
(laut Studienverlaufsplan)
1</td><td>Designated term
(laut Studienverlaufsplan)
1</td><td>Credit Points
(LP)
6 LP</td></tr>
<tr><td>10.</td><td colspan="5">Module frequency
Annually in winter term</td></tr>
<tr><td>11.</td><td colspan="5">Persons responsible for this module and full-time lecturers
Responsible: Prof. Dr. J. Walz
Lecturers: All lecturers in experimental physics</td></tr>
<tr><td>12.</td><td colspan="5">Auxiliary Information
Course language: English
Literature: Textbooks on quantum optics and light-atom interaction,
• Introductory quantum optics, Gerry & Knight
• The Quantum theroy of light, Loudon
• Quantum optics, Scully & Zubairy
• Quantum optics, Walls & Milburn
• Atom photon interactions, Cohen-Tannoudji, Dupont-Roc & Grynberg</td></tr>
</table>

Module Topical Courses: “Photonics (Q-Ex-2)”					
ID number (JOGU-StINe) 08.128.803		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises “Photonics” (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The students shall be introduced to the advanced description of light propagation and the interaction with matter. A deep understanding of laser spectroscopy – based on incoherent and coherent licht-matter interaction and highly stable lasers shall be acquired; in particular the difference between coherent and incoherent processes will be detailed. The students should learn to understand the working principle of lasers and fundamentals of non-linear optics.				
4.	Course content Fundamentals of experimental quantum physics. Possible topics: • Gaussian optics and resonators • connection between classical, semi-calssical and quantum mechanical description of light-matter interaction • coherent light and lasers • laser modulators, optical fibers • short pulses and frequency comb techniques • incoherent spectroscopy techniques (absorption, fluorescence, Doppler-free, frequency modulation) • comparison with coherent techniques (Rabi, Ramsey, Spin-Echo) • non-linear media, sum- and difference frequency generation, $\chi^{(2)}$ vs. $\chi^{(3)}$ processes, • laser cooling				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Experimental physics 3 “Waves and Quantum Mechanics”, Experimental Physics 5a “Atomic and Quantum Physics”, Theoretical Physics 3 “Quantum Mechanics”				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Annually in summer term				

Module Topical Courses: "Photonics (Q-Ex-2)"				
ID number (JOGU-StINe) 08.128.803	Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP

11. Persons responsible for this module and full-time lecturers

Responsible: Prof. Dr. K. Wendt, Prof. Dr. J, Walz

Lecturers: All lecturers in experimental physics

12. Auxiliary Information

Course language: English

Literature: Specialized textbooks in photonics , e.g.

- Laser Spectroscopy, W. Demtröder
- Optics, Light and Lasers, D. Meschede
- Lasers, A.E. Siegman
- Fundamentals of Photonics, B. E. A. Saleh und M.C. Teich
- publications close to current research.

Module Topical Courses: "Quantum Information (Q-Ex-3)"					
ID number (JOGU-StINe) 08.128.804		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Quantum Information " (WP), frequently joint theoretical-experimental course Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences Based on their knowledge of atomic and quantum physics as well as quantum mechanics, the students will study and derive the basic theoretical concepts of quantum information processing and quantum computing. On the experimental side, concepts, experimental realizations, platforms and applications of these concepts will be introduced involving the necessary aspects of quantum optics.				
4.	Course content Advanced course in the field of quantum optics, atomic physics and its application to quantum information. "Stand-alone" course, applies concepts from Quantum Optics and many boy physics. Interdisciplinary course, frequently lectured jointly by experimentalists and theorists. Contents: • storage and processing to quantum information in different systems • lead to quantum communication and computing • entangled states, quantum jumps, quantum Zeno effect • decoherence, macroscopical quantum superposition ("Schrödinger cat states") Further possible topics: • quantum gates and algorithms • quantum cryptography, quantum teleportation, quantum repeaters • error correction, error prone quantum processing • quantum simulation • Systems: ion trap, in particular Paul trap based quantum computers, cavity QED, linear optical quantum computers, neutral atoms in optical lattices, solid state and superconducting quantum processors.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Experimental Physics 5a "Atomic and Quantum Physics", Theoretical Physics 3 "Quantum Mechanics"				
7.	Entry requirements				

Module Topical Courses: "Quantum Information (Q-Ex-3)"				
ID number (JOGU-StINe) 08.128.804	Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP

8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses
9.	Weighting of the achievement in the overall grade 6/120
10.	Module frequency Annually in summer term
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. F. Schmidt-Kaler Lecturers: Selected lecturers in experimental physics, WA Quantum
12.	Auxiliary Information Course language: English Literature: Text books on quantum optics and quantum information processing, e.g. • Introductory quantum optics, Gerry & Knight • Quantum Computation and Quantum Information, Nielsen & Chuang • Introduction to Quantum Computation and Quantum Information, Lo, Popescu & Spiller • The Physics of Quantum Information, Bouwmeester, Ekert & Zeilinger • Exploring the Quantum - Atoms, Cavities and Photons, Haroche & Raimond

Module Topical Courses: “Precision fundamental physics (Q-Ex-4)”

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.805	180 h	1	1	6 LP

	Courses/Teaching methods	Contact time	Self-study	Credit Points
1.	Lecture with excercises “Precision fundamental physics” (WP) Lecture (WP) Excercises (WP)	 3 SWS/31.5 h 1 SWS/10.5 h	138 h	6 LP

2. Group sizes

Lecture: unlimited
Excercises: 20

3. Qualification and program goals / Competences

Current dedicated measurements have reached fascinating levels of experimental precision and can explore fundamental questions of physics and cosmology. These include: fundamental symmetries of physics, precision measurements in neutron decay, tests of the weak interaction, tests of CPT invariance, precision measurements of fundamental constants, and modern experiments in gravitation. The students shall be introduced to problems of modern atomic physics, quantum physics, neutron physics, and cosmology. The students shall profoundly deal with these topics, close to current research.

4. Course content

Discrete symmetries and fundamental interactions in physics

- tests of QED and CP violation, CPT-invariance, time reversal symmetry
- weak interaction, matter/ antimatter asymmetry, EDM
- variation of fundamental constants tests of the equivalence principle, Newton’s gravitation law at short distances

Methods

- Atoms, neutrons, protons, antimatter, penning traps, mass spectrometry

Neutron Physics

- the neutron as probe – structure analysis of matter, properties of the neutron and measurements, interaction with matter, neutron sources, detectors, quantum effects in neutron optics

5. Applicable to the following programs

MSc. Physics

6. Recommended prerequisites

7. Entry requirements

8. Mode and duration of examinations

8.1 Active participation

successful completion of the exercises

8.2 Course achievements

8.3 Module examination

Common oral examination (30 – 45 Min.) covering two topical courses

9. Weighting of the achievement in the overall grade

6/120

10. Module frequency

Annually in winter term

Module Topical Courses: "Precision fundamental physics (Q-Ex-4)"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.805	180 h	1	1	6 LP

11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. J. Walz Lecturers: All lecturers in experimental physics
12.	Auxiliary Information Course language: English Literature: • Textbooks in atomics physics • proceedings of summer-schools • publications close to current research.

3.3.3 Nuclear and Particle Physics

Module Topical Courses: "Statistics, Data Analysis and Simulation"					
ID number (JOGU-StINe) 08.128.730		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Statistics, Data Analysis and Simulation" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The course provides an overview of the statistical methods to analyze data and offers an introduction to Monte Carlo techniques. While the methods are often introduced with the help of examples taken from the areas of particle, hadronic and nuclear physics, we recommend the lectures also to students specializing in other fields. The goal of the course is to provide a solid basis that helps to successfully complete a master's thesis in a related area of physics.				
4.	Course content The following areas shall be covered: • Probability distributions and the statistical description of data; • error propagations and the estimation of parameters; • significance levels and decisions on hypotheses; • Monte Carlo methods, as well as • Statistical analysis methods.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Every summer semester				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. M. Schott Lecturers: All lecturers in experimental nuclear and particle physics				

Module Topical Courses: "Statistics, Data Analysis and Simulation"				
ID number (JOGU-StINe) 08.128.730	Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP

12. Auxiliary Information

Course language: English

Literature:

- R.J. Barlow, Statistics
- Glen Cowan, Statistical data analysis
- Olaf Behnke, Data analysis in high energy physics

<table>
<tr><th colspan="6">Module Topical Courses: “Particle Detectors”</th></tr>
<tr><td colspan="2">ID number
(JOGU-StINe)
08.128.731</td><td>Workload
(workload)
180 h</td><td>Course Duration
(laut Studienverlaufsplan)
1</td><td>Designated term
(laut Studienverlaufsplan)
1</td><td>Credit Points
(LP)
6 LP</td></tr>
<tr><td>1.</td><td colspan="2">Courses/Teaching methods
Lecture with excercises “Particle Detectors” (WP)
Lecture (WP)
Excercises (WP)</td><td>Contact time

3 SWS/31.5 h
1 SWS/10.5 h</td><td>Self-study
138 h</td><td>Credit Points
6 LP</td></tr>
<tr><td>2.</td><td colspan="5">Group sizes
Lecture: unlimited
Excercises: 20</td></tr>
<tr><td>3.</td><td colspan="5">Qualification and program goals / Competences
The course provides an overview of the detection, read-out and analysis techniques used in particle, hadron, nuclear, and astroparticle physics. The goal is to provide a solid basis for the successful completion of a master’s thesis. Cross disciplinary aspects (solid state physics, electronics, mathematics, and computer science) play important roles. Therefore the course is also suitable to students that focus on other areas of physics.</td></tr>
<tr><td>4.</td><td colspan="5">Course content
The following subjects shall be covered:
• Particle sources and accelerators;
• Detection methods for charged and neutral radiation;
• Data acquisition;
• Particle detectors to measure time, energy, momentum and particle type;
• Applications in complex detector systems.</td></tr>
<tr><td>5.</td><td colspan="5">Applicable to the following programs
MSc. Physics</td></tr>
<tr><td>6.</td><td colspan="5">Recommended prerequisites</td></tr>
<tr><td>7.</td><td colspan="5">Entry requirements</td></tr>
<tr><td>8.</td><td colspan="5">Mode and duration of examinations
8.1 Active participation
successful completion of the exercises
8.2 Course achievements

8.3 Module examination
Common oral examination (30 – 45 Min.) covering two topical courses</td></tr>
<tr><td>9.</td><td colspan="5">Weighting of the achievement in the overall grade
6/120</td></tr>
<tr><td>10.</td><td colspan="5">Module frequency
Every winter semester</td></tr>
<tr><td>11.</td><td colspan="5">Persons responsible for this module and full-time lecturers
Responsible: Prof. Dr. M. Schott
Lecturers: All lecturers in experimental nuclear and particle physics</td></tr>
</table>

Module Topical Courses: "Particle Detectors"				
ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.731	180 h	1	1	6 LP

12.	Auxiliary Information Course language: English Literature: • K. Kleinknecht, Detectors for particle radiation • C. Grupen, B. Shwartz, Particle Detectors

Module Topical Courses: "Cosmology and General Relativity"					
ID number (JOGU-StINe) 08.128.732		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Cosmology and General Relativity" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The lectures' program goal is to provide a basic understanding of the theory of General Relativity as well as of the current concepts and phenomena of cosmology.				
4.	Course content General coordinate transformations, differential geometry, Einstein equation, Schwarzschild metric, black holes, Friedmann-Robertson-Walker cosmology, big-bang nucleosynthesis, cosmic microwave background, structure development in the early universe, dark matter and dark energy.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. M. Neubert Lecturers: Häusling, Neubert, Papadopoulos, Reuter, Spiesberger, Weinzierl				
12.	Auxiliary Information Course language: English Literature: e.g. Carroll, Wald, Kolb & Turner, Dodelson				

Module Topical Courses: "Symmetries in Physics"					
ID number (JOGU-StINe) 08.128.733		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Symmetries in Physics" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The lectures' program goal is to provide a basic understanding of group theory and its' applications in physics.				
4.	Course content Group theory, representations, unitary symmetries, Lie groups, applications and exercises in particle and nuclear physics.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. M. Neubert Lecturers: Neubert, Scherer, Spiesberger, Weinzierl				
12.	Auxiliary Information Course language: English Literature: e.g. Georgi, Tung				

Module Topical Courses: "Modern Methods in Theoretical High Energy, Particle and Nuclear Physics"					
ID number (JOGU-StINe) 08.128.734		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Modern Methods in Theoretical High Energy, Particle and Nucle-ar Physics" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The lectures' program goal is to provide a basic understanding of a topic related to current research in the field of high energy, particle and nuclear physics. An additional goal is to teach the methods which are required for the masters's thesis.				
4.	Course content Concerning to the lecturer the focus is put on a current scientifical topic from the following research areas: electroweak and strong interactions, lattice gauge theory, effective field theories, mathematical aspects of perturbation theory, functional integration in quantum mechanics und quantum field theory, concepts of model building beyond the standard model (e.g. supersymmetry, string theory) and others. Lectures of this module are offered by different lecturers and topics can change every semester. In this case a student can subscribe to this module more than once and the module will not be counted as identical.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. M. Neubert, Prof. Dr. H. Wittig Lecturers: All lecturers in theoretical nuclear and particle physics				
12.	Auxiliary Information Course language: English Literature: various textbooks, publications close to science				

Module Topical Courses: "Accelerator Physics"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.735	180 h	1	1	6 LP

	Courses/Teaching methods	Contact time	Self-study	Credit Points
1.	Lecture with excercises "Accelerator Physics" (WP) Lecture (WP) Excercises (WP)	 3 SWS/31.5 h 1 SWS/10.5 h	138 h	6 LP

2. Group sizes

Lecture: unlimited
Excercises: 20

3. Qualification and program goals / Competences

The purpose of the lecture is to provide an understanding of the underlying physical principles of modern particle accelerators and radiation sources. This concerns in particular the layout of pivotal components such as magnetic structures and radiofrequency-systems. Another objective is to teach the mathematical framework with respect to analytical and numerical methods. Such knowledge will form a suitable basis for doing a master's thesis within the accelerator physics groups at Mainz university.

4. Course content

Linear and non linear beam-dynamics, in conjunction with properties of linear and recirculating accelerators. Building blocks of beam transport systems, e.g. normal und superconducting magnets. Radiofrequency systems for charged particle acceleration, including superconducting systems. Introduction to superconductivity. Introduction to radiation physics (Synchrotron-radiation), Collective effects, e.g. free electron laser. Recent developments such as energy recovery linacs.

5. Applicable to the following programs

MSc. Physics

6. Recommended prerequisites

7. Entry requirements

8. Mode and duration of examinations

8.1 Active participation

successful completion of the exercises

8.2 Course achievements

8.3 Module examination

Common oral examination (30 – 45 Min.) covering two topical courses

9. Weighting of the achievement in the overall grade

6/120

10. Module frequency

Every winter semester

11. Persons responsible for this module and full-time lecturers

Responsible: Prof. Dr. K. Aulenbacher
Lecturers: Prof. Dr. K. Aulenbacher

12. Auxiliary Information

Course language: English
Literature:

- H. Wiedemann, Particle Accelerator Physics Bd. 1&2

Module Topical Courses: “Astroparticle Physics”

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.737	180 h	1	1	6 LP

	Courses/Teaching methods	Contact time	Self-study	Credit Points
1.	Lecture with excercises “Astroparticle Physics” (WP)		138 h	6 LP
	Lecture (WP)	3 SWS/31.5 h		
	Excercises (WP)	1 SWS/10.5 h		

2. Group sizes

Lecture: unlimited
Excercises: 20

3. Qualification and program goals / Competences

The course provides an overview of cosmology and astroparticle physics and of topical research themes. It provides essential knowledge to successfully complete a master’s thesis in a related subject area.

4. Course content

The main themes of the course relate to:

- Cosmology and the evolution of the Universe
- Dark matter and
- Cosmic radiation of charged particles, neutrinos, and gammas as well as gravitational waves.

The subject “cosmology and evolution of the universe“ covers cosmological models and parameters, cosmological distances and related measurements, the matter/antimatter problem, the synthesis of light elements, the microwave background radiation, structure formation, the formation, classification, development of galaxies, active galactic nuclei and galaxy clusters, as well as the formation, energy budget, development, and final stages of stars, including the related nucleosynthesis. The theme “dark matter"covers the evidence, as well as direct and indirect searches performed to detect viable particle candidates. Keywords important for the chapter on “cosmic rays” are: sources, composition, propagation, and detection of charged cosmic radiation, sources and detection of resolved and diffuse gamma-ray sources, determination of neutrino properties (oscillations, direct mass measurement, neutrino-less double beta decay), sources and detection of terrestrial and astrophysical neutrinos, the theory and prospective sources of gravitational waves, as well as their indirect and direct detection.

5. Applicable to the following programs

MSc. Physics

6. Recommended prerequisites

Knowledge equivalent to module Experimental Physics 5b “Nuclear and Particle Physics”

7. Entry requirements

8. Mode and duration of examinations

8.1 Active participation

successful completion of the exercises

8.2 Course achievements

8.3 Module examination

Common oral examination (30 – 45 Min.) covering two topical courses

9. Weighting of the achievement in the overall grade

6/120

Module Topical Courses: "Astroparticle Physics"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.737	180 h	1	1	6 LP

10.	Module frequency Every summer semester
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. U. Oberlack Lecturers: Prof. S. Böser, Apl Prof. Dr. Egelhoff, Apl Prof. Dr. Kabuss, Prof. U. Oberlack, Prof. M. Wurm.
12.	Auxiliary Information Course language: English Literature: • A. Liddle, An introduction to modern cosmology • P. Schneider, Extragalaktische Astronomie und Kosmologie • C. Grupen, Astroteilchenphysik • D. Perkins, Particle Astrophysics

Module Topical Courses: "Particle Physics"					
ID number (JOGU-StINe) 08.128.738		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Particle Physics" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The course is intended to deepen the understanding of the fundamental building blocks of matter and their interactions. Basic principles will be covered by using topical research as an example. The course provides the required knowledge in order to successfully complete a master's thesis in a related subject.				
4.	Course content The following subjects shall be covered: • Brief outline of experimental methods, • Symmetries and the quark model, • Lepton scattering at high energies, • Particles and interaction in the Standard Model, as well as models for its unification and extension. While covering the subjects, ground breaking and actual experiments will be discussed. Depending on the docent's interest, extension of the Standard Mode or bound systems will be covered in more detail.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Knowledge equivalent to module Experimental Physics 5b "Nuclear and Particle Physics"				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Every semester				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. M. Schott Lecturers: All lecturers in experimental nuclear and particle physics				

Module Topical Courses: "Particle Physics"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.738	180 h	1	1	6 LP

12.	Auxiliary Information Course language: English Literature: • C. Berger, Elementarteilchenphysik, Springer-Verlag, 2006. • D. Griffiths, Introduction to Elementary Particles, Wiley-VCH Verlag, 2008. • E. Lohrmann, Hochenergiephysik, Teubner-Verlag, 2005. • D. H. Perkins, High Energy Physics • B. Povh et al., Teilchen und Kerne

Module Topical Courses: "Theoretical Particle Physics"					
ID number (JOGU-StINe) 08.128.809		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Theoretical Particle Physics" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The lecture course "Theoretical Particle Physics" builds upon and continues the lecture course "Relativistic Quantum Field Theory". The lectures' program goal is to provide a basic understanding of concepts and methods of quantum field theory which are required for a MA thesis in theoretical particle physics.				
4.	Course content Path integral formalism, quantum corrections, renormalization in QED, renormalization group; non-Abelian gauge theories, quantum chromodynamics (QCD), spontaneous symmetry breaking, Higgs mechanism, standard model of particle physics.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Usually every semester				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. S. Weinzierl Lecturers: All professors of theoretical high energy physics				
12.	Auxiliary Information Course language: English Literature: Peskin & Schroeder, Ryder, Schwartz, Zee				

Module Topical Courses: "Theoretical Nuclear Physics"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.751	180 h	1	1	6 LP

	Courses/Teaching methods	Contact time	Self-study	Credit Points
1.	Lecture with excercises "Theoretical Nuclear Physics" (WP) Lecture (WP) Excercises (WP)	 3 SWS/31.5 h 1 SWS/10.5 h	138 h	6 LP

2.	Group sizes Lecture: unlimited Excercises: 20
3.	Qualification and program goals / Competences The aim of this course is to provide students with a survey of nuclear theory at the graduate level, as well as an introduction to modern nuclear theories and topics. While the focus is on theoretical aspects of nuclear physics, when possible, the subject will be linked to recent experimental progress and applications, e.g. to astrophysics.
4.	Course content Introduction to nuclei and nuclear forces, Theory for alpha, beta and gamma decays, Types of nuclear spectra and EM transitions, Few-body methods for nuclei, Many-body methods for nuclei, Nuclear reactions, Nuclear astrophysics and formation of the elements.
5.	Applicable to the following programs MSc. Physics
6.	Recommended prerequisites
7.	Entry requirements
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses
9.	Weighting of the achievement in the overall grade 6/120
10.	Module frequency Winter semester
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. S. Bacca Lecturers: Prof. Dr. S. Bacca and Prof. Dr. P. Capel
12.	Auxiliary Information Course language: English Literature: Text books on nuclear physics, e.g. • Samuel S.M. Wong, Introductory Nuclear Physics. • Carlos A. Bertulani, Nuclear Physics in a Nutshell. • Kenneth S. Krane, Introductory Nuclear Physics.

Module Topical Courses: "Introduction to Lattice Gauge Theory"					
ID number (JOGU-StINe) 08.128.746		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Introduction to Lattice Gauge Theory" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The lectures' program goal is to provide a basic understanding of the methods of lattice gauge theory and its applications to problems in particle and nuclear physics. A particular goal is to teach the methods which are required for pursuing a master's thesis in this field.				
4.	Course content Discretization of PDEs by finite differences; path integral in quantum mechanics; Euclidean correlation functions in QFT; transfer matrix; scalar field theories on the lattice and spin models; Ising model at high and low temperature; Z_2 lattice gauge theory, Elitzur's theorem and Wegner loop; QED and QCD in the continuum; Wilson loop; lattice gauge theory with Wilson action; Haar measure; fermions on the lattice; static potential and strong-coupling expansion; renormalization group and continuum limit; lattice perturbation theory; Monte Carlo simulations and determination of hadronic properties.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Theoretical Physics 6 (Quantum Field Theory)				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Irregular				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. H. Wittig Lecturers: Prof. Dr. H. Wittig, Prof. Dr. H. Meyer, PD Dr. G. von Hippel				

Module Topical Courses: "Introduction to Lattice Gauge Theory"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.746	180 h	1	1	6 LP

12. Auxiliary Information

Course language: English

Literature:

- C. Gattringer and C.B. Lang, Quantum Chromodynamics on the Lattice (Lect. Notes Phys. 788), Springer, Berlin Heidelberg 2010.
- J. Smit, Introduction to Quantum Fields on a Lattice: a robust mate (Cambridge Lect. Notes Phys. 15), Cambridge University Press 2002.
- I. Montvay and G. Münster, Quantum Fields on a Lattice, Cambridge University Press 1994.
- J.B. Kogut, An Introduction to Lattice Gauge Theory and Spin Systems, Rev. Mod. Phys. 51 (1979) 659.

<table>
<tr><td colspan="6">Module Topical Courses: “Introduction to String Theory”</td></tr>
<tr><td colspan="2">ID number
(JOGU-StINe)
08.128.760</td><td>Workload
(workload)
180 h</td><td>Course Duration
(laut Studienverlaufsplan)
1</td><td>Designated term
(laut Studienverlaufsplan)
1</td><td>Credit Points
(LP)
6 LP</td></tr>
<tr><td>1.</td><td colspan="2">Courses/Teaching methods
Lecture with excercises “Introduction to String Theory” (WP)
Lecture (WP)
Excercises (WP)</td><td>Contact time

3 SWS/31.5 h
1 SWS/10.5 h</td><td>Self-study
138 h</td><td>Credit Points
6 LP</td></tr>
<tr><td>2.</td><td colspan="5">Group sizes
Lecture: unlimited
Excercises: 20</td></tr>
<tr><td>3.</td><td colspan="5">Qualification and program goals / Competences
The lectures’ program goal is to provide a basic understanding of classical and quantised bosonic and fermionic string theories. An additional goal is to teach methods which are required for the maters’s thesis.</td></tr>
<tr><td>4.</td><td colspan="5">Course content
Classical bosonic string, quantisation (lightcone, covariant, path integral, BRST formalism), D-branes, superstrings, introduction to conformal field theory, string amplitudes.</td></tr>
<tr><td>5.</td><td colspan="5">Applicable to the following programs
MSc. Physics</td></tr>
<tr><td>6.</td><td colspan="5">Recommended prerequisites
Recommended, but not required: Theoretical Physics 6 (Quantum Field Theory), Cosmology and General Relativity</td></tr>
<tr><td>7.</td><td colspan="5">Entry requirements</td></tr>
<tr><td>8.</td><td colspan="5">Mode and duration of examinations
8.1 Active participation
successful completion of the exercises
8.2 Course achievements

8.3 Module examination
Common oral examination (30 – 45 Min.) covering two topical courses</td></tr>
<tr><td>9.</td><td colspan="5">Weighting of the achievement in the overall grade
6/120</td></tr>
<tr><td>10.</td><td colspan="5">Module frequency
Irregular</td></tr>
<tr><td>11.</td><td colspan="5">Persons responsible for this module and full-time lecturers
Responsible: Prof. Dr. G. Honecker
Lecturers: All professors of theoretical high energy physics</td></tr>
</table>

Module Topical Courses: "Introduction to String Theory"				
ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.760	180 h	1	1	6 LP

12. Auxiliary Information

Course language: English

Literature: various textbooks, publications close to science, e.g.:

- Zwiebach: A First Course in String Theory, Cambridge University Press 2004;
- Blumenhagen, Lüst, Theisen: Basic Concepts of String Theory, Springer 2012;
- Polchinski: String Theory, Vol. 1 & 2, Cambridge University Press 1998;
- Green, Schwarz, Witten: String Theory, Vol. 1 & 2, Cambridge University Press 1987;
- Becker, Becker, Schwarz: String Theory and M-Theory - A Modern Introduction, Cambridge University Press 2007

<table>
<tr><th colspan="6">Module Topical Courses: “Effective Field Theories”</th></tr>
<tr><td colspan="2">ID number
(JOGU-StINe)
08.128.766</td><td>Workload
(workload)
180 h</td><td>Course Duration
(laut Studienverlaufsplan)
1</td><td>Designated term
(laut Studienverlaufsplan)
1</td><td>Credit Points
(LP)
6 LP</td></tr>
<tr><td>1.</td><td colspan="2">Courses/Teaching methods
Lecture with excercises “Effective Field Theories” (WP)
Lecture (WP)
Excercises (WP)</td><td>Contact time

3 SWS/31.5 h
1 SWS/10.5 h</td><td>Self-study
138 h</td><td>Credit Points
6 LP</td></tr>
<tr><td>2.</td><td colspan="5">Group sizes
Lecture: unlimited
Excercises: 20</td></tr>
<tr><td>3.</td><td colspan="5">Qualification and program goals / Competences
The lectures introduce the basic ideas of the effective field theory approach like relevant and irrelevant operators, renormalization group, decoupling of heavy particle. The lectures also provide a deeper understanding of its most important applications in modern research fields.</td></tr>
<tr><td>4.</td><td colspan="5">Course content
The method of effective field theory provides a systematic approach to multi-scale problems. An effective field theory uses the appropriate degrees of freedom to describe the phenomena at a given energy scale, while all degrees of freedom only relevant at much higher scales are eliminated from the theory. These concepts lead to a large variety of phenomenological applications in modern particle physics. Especially in the theory of strong interactions with its different behaviour at the various energy scales the important examples of the electroweak Lagrangian, heavy-quark-effective theory, and soft-collinear-effective theories allow for most suitable descriptions of the respective theoretical systems.</td></tr>
<tr><td>5.</td><td colspan="5">Applicable to the following programs
MSc. Physics</td></tr>
<tr><td>6.</td><td colspan="5">Recommended prerequisites
Theoretical Physics 6 (Quantum Field Theory)</td></tr>
<tr><td>7.</td><td colspan="5">Entry requirements</td></tr>
<tr><td>8.</td><td colspan="5">Mode and duration of examinations
8.1 Active participation
successful completion of the exercises
8.2 Course achievements

8.3 Module examination
Common oral examination (30 – 45 Min.) covering two topical courses</td></tr>
<tr><td>9.</td><td colspan="5">Weighting of the achievement in the overall grade
6/120</td></tr>
<tr><td>10.</td><td colspan="5">Module frequency
Irregular</td></tr>
<tr><td>11.</td><td colspan="5">Persons responsible for this module and full-time lecturers
Responsible: Prof. Dr. M. Neubert
Lecturers: All professors of theoretical high energy and hadron physics</td></tr>
</table>

Module Topical Courses: "Effective Field Theories"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.766	180 h	1	1	6 LP

12. Auxiliary Information

Course language: English

Literature:

- Lecture notes Ëffective Field Theory"by A. Pich
- Lecture notes Ëffective Field Theories"by A. Manohar
- Lecture notes Ëffective Field Theories and Heavy Quark Physics"by M. Neubert

<table>
<tr><th colspan="6">Module Topical Courses: “Theoretical Astroparticle Physics”</th></tr>
<tr><td colspan="2">ID number
(JOGU-StINe)
08.128.762</td><td>Workload
(workload)
180 h</td><td>Course Duration
(laut Studienverlaufsplan)
1</td><td>Designated term
(laut Studienverlaufsplan)
1</td><td>Credit Points
(LP)
6 LP</td></tr>
<tr><td>1.</td><td colspan="2">Courses/Teaching methods
Lecture with excercises “Theoretical Astroparticle Physics” (WP)
Lecture (WP)
Excercises (WP)</td><td>Contact time

3 SWS/31.5 h
1 SWS/10.5 h</td><td>Self-study
138 h</td><td>Credit Points
6 LP</td></tr>
<tr><td>2.</td><td colspan="5">Group sizes
Lecture: unlimited
Excercises: 20</td></tr>
<tr><td>3.</td><td colspan="5">Qualification and program goals / Competences
This lecture aims to give, from a theorists point of view, a broad but thorough overview of state of the art astroparticle physics. Its goal is to prepare students to understand the current scientific literature on cosmology, dark matter, neutrinos and related topics and to prepare them for their own research projects (Master / PhD) in experimental or theoretical astroparticle physics.</td></tr>
<tr><td>4.</td><td colspan="5">Course content
The big bang theory (Friedmann equation, expansion of the Universe); big bang nucleosynthesis; cosmic microwave background; formation of structure in the Universe; dark matter (production in the early Universe by thermal freeze-out, searches in terrestrial and astrophysical experiments); the cosmic matter-antimatter asymmetry; high energy cosmic rays; neutrinos (mechanisms to explain the smallness of neutrino masses; theory and phenomenology of neutrino oscillations; impact of neutrinos on cosmology; supernova neutrinos); axions</td></tr>
<tr><td>5.</td><td colspan="5">Applicable to the following programs
MSc. Physics</td></tr>
<tr><td>6.</td><td colspan="5">Recommended prerequisites
Theoretical Physics 6 (Quantum Field Theory)</td></tr>
<tr><td>7.</td><td colspan="5">Entry requirements</td></tr>
<tr><td>8.</td><td colspan="5">Mode and duration of examinations
8.1 Active participation
successful completion of the exercises
8.2 Course achievements

8.3 Module examination
Common oral examination (30 – 45 Min.) covering two topical courses</td></tr>
<tr><td>9.</td><td colspan="5">Weighting of the achievement in the overall grade
6/120</td></tr>
<tr><td>10.</td><td colspan="5">Module frequency
Irregular</td></tr>
<tr><td>11.</td><td colspan="5">Persons responsible for this module and full-time lecturers
Responsible: Prof. Dr. J. Kopp
Lecturers: All professors of theoretical high energy physics</td></tr>
<tr><td>12.</td><td colspan="5">Auxiliary Information
Course language: English
Literature: various textbooks, publications close to science</td></tr>
</table>

Module Topical Courses: "Amplitudes and Precision Physics at the LHC"					
ID number (JOGU-StINe) 08.128.764		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Amplitudes and Precision Physics at the LHC" (WP) Lecture (WP) Excercises (WP)	Contact time 3 SWS/31.5 h 1 SWS/10.5 h		Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The goal of this lecture is to introduce students to recently developed methods for calculating scattering amplitudes within quantum field theory. A particular emphasis is put on the efficiency of the methods to be used. These new methods allow to predict cross sections for the experiments at the LHC, which are difficult to compute with traditional methods.				
4.	Course content Spin- and helicity methods, colour decomposition, off-shell recursion relations, on-shell recursion relations, scattering equations; loop integrals, differential equations for loop integrals, classes of functions (for example multiple polylogarithms).				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Theoretical Physics 6 (Quantum Field Theory)				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Irregular				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. J. Henn, Prof. Dr. S. Weinzierl Lecturers: All professors of theoretical high energy physics				
12.	Auxiliary Information Course language: English Literature: • J. Henn, J. Plefka, „Scattering Amplitudes in Gauge Theories“, Springer, 2014; • H. Elvang, Y. Huang, „Scattering Amplitudes in Gauge Theory and Gravity“, Cambridge University Press, 2015; • L. Dixon, „Calculating Scattering Amplitudes Efficiently“, arxiv.org/abs/hep-ph/9601359				

Module Topical Courses: "Functional Methods and Exact Renormalization Group"					
ID number (JOGU-StINe) 08.128.747		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 1	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Functional Methods and Exact Renormalization Group" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The goal of this lecture is to introduce students to path integrals, functional integral quantization of field theories and the functional renormalization group equation.				
4.	Course content (A) Path integrals in quantum mechanics: • Relation to the canonical approach, discretization and operator ordering, topological aspects (multiply connected configuration spaces, etc.), evaluation of functional integrals (exactly soluble examples, semiclassical expansion, perturbation theory), instantons in quantum mechanics (double well, periodic potentials, n- and Theta-vacua). (B) Functional integral quantization of field theories: • Functional Schroedinger picture, wave functionals, field-particle relationship, symmetry and covariance properties, from transition amplitudes to (vacuum-) correlators and generating functionals, the Schwinger-Symanzik approach, functional integral representation via the Schroedinger picture and the Schwinger-Symanzik approach, the effective action (canonical and diagrammatic approaches, Legendre-Fenchel transform), computational techniques (semiclassical and perturbative expansion), perturbative Yang-Mills theory, nonperturbative Yang-Mills theory ("large"gauge transformations, homotopy classes- and groups, instantons and tunneling, nonperturbative vacuum structure). (C) The functional renormalization group equation (FRGE): • Functional (i.e. "exact") vs. perturbative renormalization, critical phenomena, Wilsonian renormalization group in statistical mechanics and quantum field theory (theory space, block spin transformations, coupling constant flows), notions of nonperturbative renormalizability, continuum limits and phase transitions, construction and "solution" of quantum field theories by means of FRGE methods.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Theoretical Physics 6 (Quantum Field Theory)				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Common oral examination (30 – 45 Min.) covering two topical courses				

Module Topical Courses: "Functional Methods and Exact Renormalization Group"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.747	180 h	1	1	6 LP

9.	Weighting of the achievement in the overall grade 6/120
10.	Module frequency Irregular
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. M. Reuter Lecturers: All professors of theoretical high energy physics
12.	Auxiliary Information Course language: English

Module Advanced Course: "Advanced Particle Physics"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.806	180 h	1	2	6 LP

	Courses/Teaching methods	Contact time	Self-study	Credit Points
1.	Lecture with excercises "Advanced Particle Physics" (WP)		138 h	6 LP
	Lecture (WP)	3 SWS/31.5 h		
	Excercises (WP)	1 SWS/10.5 h		

2.	Group sizes Lecture: unlimited Excercises: 20
3.	Qualification and program goals / Competences This course covers special aspects of the fundamental building blocks of matter and their interactions in detail. The newest experimental methods and results will be presented for topical research areas in particle physics. The course provides the students with advanced knowledge that will help in completing an experimental master's thesis in a related research area.
4.	Course content The content of the course is variable and will typically include one of the following subjects: • Lepton scattering at high energies, • Strong interaction, • Electro-weak interaction, as well as • Models for the unification and extrension of the Standard Model.
5.	Applicable to the following programs MSc. Physics
6.	Recommended prerequisites Knowledge on the level of the module Experimental Physics 5b "Nuclear and Particle Physics" is strongly recommended. Helpful, however not essential, is the successful completion of the Topical Course "Elementary Particle Physics".
7.	Entry requirements
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Written exam (90-180 Min.) or oral examination (30 Min.)
9.	Weighting of the achievement in the overall grade 6/120
10.	Module frequency irregular
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. M. Schott Lecturers: All lecturers in experimental particle physics

Module Advanced Course: "Advanced Particle Physics"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.806	180 h	1	2	6 LP

12.	Auxiliary Information Course language: English Literature: • C. Berger, Elementarteilchenphysik • D. Griffiths, Introduction to Elementary Particles Recommendations for specialized books and recent publication on current topics will be provided.

Module Advanced Course: "Advanced Chapters on Subatomic Physics"					
ID number (JOGU-StINe) 08.128.807		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 2	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises "Advanced Chapters on Subatomic Physics" (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The lecture intends to provide a deep understanding on research-oriented topics of hadron physics. Basic concepts as well as research topics will be presented. The lecture will provide the essential knowledge necessary to successfully complete an experimental master's thesis in related fields.				
4.	Course content Current experimental methods, electromagnetic and hadronic probes, polarization experiments; resonances, decays, form factors and structure functions of hadrons; effective theories; spectroscopy, symmetry and structures of hadrons, the impact of hadron physics on precision tests of the Standard Model. Key experiments will be discussed for all topics.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites Knowledge at the level of Experimental Physics 5 "Nuclear and Particle Physics".				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Written exam (90-180 Min.) or oral examination (30 Min.)				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency				
11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. A. Denig Lecturers: from the field of experimental nuclear and particle physics				
12.	Auxiliary Information Course language: English Literature: Several text books, e.g. • B. Povh et al., Teilchen und Kerne • D. H. Perkins, High Energy Physics • W. Thomas und W. Weise, The Structure of the Nucleon				

Module Advanced Course: "Advanced Astroparticle- and Astrophysics"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.808	180 h	1	2	6 LP

	Courses/Teaching methods	Contact time	Self-study	Credit Points
1.	Lecture with excercises "Advanced Astroparticle- and Astrophysics" (WP)		138 h	6 LP
	Lecture (WP)	3 SWS/31.5 h		
	Excercises (WP)	1 SWS/10.5 h		

2. Group sizes

Lecture: unlimited

Excercises: 20

3. Qualification and program goals / Competences

This course covers special aspects of astroparticle physics and astrophysics, thereby presenting the newest experimental methods and results. The course provides the students with advanced knowledge that will help in completing an experimental master's thesis in a related research area.

4. Course content

Depending on interest of the lecturer, the emphasis will be put on nuclear- or astrophysical aspects of the following subjects:

- Cosmology (early universe, nucleosynthesis, dark components),
- Stars (formation, energy production and development stages) or Cosmic radiation (origin, acceleration mechanisms, etc.).

5. Applicable to the following programs

MSc. Physics

6. Recommended prerequisites

Knowledge on the level of the module Experimental Physics 5b "Nuclear and Particle Physics" is strongly recommended.

7. Entry requirements

8. Mode and duration of examinations

8.1 Active participation

successful completion of the exercises

8.2 Course achievements

8.3 Module examination

Written exam (90-180 Min.) or oral examination (30 Min.)

9. Weighting of the achievement in the overall grade

6/120

10. Module frequency

irregular

11. Persons responsible for this module and full-time lecturers

Responsible: Prof. Dr. U. Oberlack

Lecturers: Prof. S. Böser, Apl Prof. Dr. Egelhoff, Apl Prof. Dr. Kabuss, Prof. Dr. Oberlack, Prof. Dr. Wurm

12. Auxiliary Information

Course language: English

Literature:

- C. Grupen, Astroteilchenphysik
- E. Rolfs und W. Rodney, Cauldrons in the Cosmos

Module Advanced Course: “Advanced Accelerator Physics”					
ID number (JOGU-StINe) 08.128.816		Workload (workload) 180 h	Course Duration (laut Studienverlaufsplan) 1	Designated term (laut Studienverlaufsplan) 2	Credit Points (LP) 6 LP
1.	Courses/Teaching methods Lecture with excercises “Advanced Accelerator Physics” (WP) Lecture (WP) Excercises (WP)		Contact time 3 SWS/31.5 h 1 SWS/10.5 h	Self-study 138 h	Credit Points 6 LP
2.	Group sizes Lecture: unlimited Excercises: 20				
3.	Qualification and program goals / Competences The first objective of the course is to understand spin-polarized ensembles. Later-on, we will discuss their behavior under the conditions of relativistic motion in macroscopic external fields. This regime is governed by the Thomas-BMT equation. The spin dynamics in spin rotators, recirculating linear accelerators, but also in particular for synchrotrons and storage rings will be discussed. The second part is devoted to the realization of spin-sensitive experiments at accelerators which are of course based on the interaction of spins with microscopic fields. Information on these interactions may be obtained by measuring spin sensitive observables, e.g. the analysing power of the process. The presentation of experimental techniques such as polarized sources and polarimeters concludes the course. The course provides the background to successfully complete a master’s thesis in the groups at MAMI that deal with experiments based on spin-polarized beams.				
4.	Course content The course will provide knowledge and competence with respect to the following subjects: Spin polarized ensembles, density matrix, Dirac’ equation, spin precession in the lab frame (Thomas BMT equation), single pass spin rotators, sibirian snakes, intrinsic and imperfection resonances in storage rings, Sokolov-Ternov effect, spinstable solutions, depolarization by synchrotron radiation, spin equilibrium, spin polarized sources, spin sensitive observables (analyzing powers), polarimetry parity violating observable, Parity violation experiments at accelerators, double polarization experiments with polarized targets at collider facilities.				
5.	Applicable to the following programs MSc. Physics				
6.	Recommended prerequisites				
7.	Entry requirements				
8.	Mode and duration of examinations *8.1 Active participation* successful completion of the exercises *8.2 Course achievements* *8.3 Module examination* Written exam (90-180 Min.) or oral examination (30 Min.)				
9.	Weighting of the achievement in the overall grade 6/120				
10.	Module frequency Every summer semester				

Module Advanced Course: "Advanced Accelerator Physics"

ID number (JOGU-StINe)	Workload (workload)	Course Duration (laut Studienverlaufsplan)	Designated term (laut Studienverlaufsplan)	Credit Points (LP)
08.128.816	180 h	1	2	6 LP

11.	Persons responsible for this module and full-time lecturers Responsible: Prof. Dr. K. Aulenbacher Lecturers: Docents representing the area
12.	Auxiliary Information Course language: English Literature: • D. Barber: Introduction to Spin polarisation in accelerators and storage rings • B.W. Montague Physics Reports 113 (1984) 1-96 • A. Lehrach: Strahl und Spin-Dynamik von Hadronenstrahlen in Mittelenergiespeicherringen. Schriften des Forschungszentrums Jülich, Reihe Schlüsseltechnologien, Jülich 2008 ISBN 978-3-89336-548-7