2023

MATHEMATISCH-
NATURWISSENSCHAFTLICHE
FAKULTÄT

UNIVERSITÄT ZU KÖLN

DEKANAT

MODULE HANDBOOK

PHYSICS

MASTER OF SCIENCE

VERSION 1.0
ACCORDING TO THE EXAMINATION REGULATIONS FOR THE MASTER PROGRAM IN PHYSICS
(AS AMENDED FROM 09.08.2023)

Universität zu Köln

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Legend

AQM	Advanced Quantum Mechanics	PW	Preparation and Wrap-up Time
ASP	Advanced Statistical Physics	SAoS	Secondary Area of Specialization
CT	Contact Time (attendance time in the course)	PS	Private Study
CP	Credit Point	SuSe	Summer Semester
HPW	Hours per Week	WL	Workload
PAoS	Primary Area of Specialization	WiSe	Winter Semester

Table of contents

1 The Field of Study Physics

The physics courses at the University of Cologne aim to equip students with the knowledge and tools for independent scientific work. In the course of their studies, they gain the qualification to actively participate in the fundamental research carried out at the physics institutes at the University of Cologne.

1.1 Contents, Objectives and Prerequisites

The master course in physics is based on the broad basic knowledge gained during bachelor studies. This knowledge of experimental and theoretical physics is deepened in practical courses, lectures, and in intensively supervised exercise classes. In addition, students focus on individual fields of physics within the primary and secondary area of specialization.

At the end of their Master studies, the students will have acquired a number of broad and focused competencies within their areas of specialization, in particular solving complex problems through a structured approach and analytical thinking. Students will have learned to successfully apply these skills to the different scientific and technical problems they will encounter in their following career, either within or outside academia. The master studies lead to a degree qualifying the graduate to enter a profession.

The requirements for admission are given in a separate set of regulations (master's admission regulations).

1.2 Structure and Sequence of Studies

The Master of Science in Physics program comprises 120 credit points and is designed for a standard period of study of four terms. Students may begin with their studies either in the winter or the summer term.

The first year of the degree program is strongly teaching-oriented. It includes the compulsory module in Advanced Theoretical Physics, the courses and examinations of the two Areas of Specialization and the Elective Area as well as the lab courses within the framework of the Practical Training modules. The courses for the Primary and Secondary Area of Specialization as well as the Elective Area can be chosen flexibly. This allows students to arrange their courses in the best order, matching their individual course choice and needs.

In contrast, the second year of the program is more research-oriented. The students deal with current research questions in an Advanced Seminar and within the scope of the Introductory Projects in the third semester as well as in the Master's thesis in the fourth semester.

For all modules of the study course, students can choose from several options:

- For the two lab courses within the Practical Training modules, students can choose between *Molecular and Astrophysics*, *Solid State Physics*, *Nuclear Physics*, *Biophysics* or *Computational Physics*.
- The course for the Advanced Theoretical Physics can be chosen as either *Advanced Quantum Mechanics (AQM)* or *Advanced Statistical Physics (ASP)*.

- The Primary and Secondary Area of Specialization (PAoS and SAoS) can be chosen from the following subjects: *Astrophysics*; *Condensed Matter Physics*; *Foundations of Quantum Technologies: Matter, Light and Information*; *Molecular Physics*; *Nuclear and Particle Physics*; *Quantum Field Theory / General Theory of Relativity*; *Solid State Theory / Computational Physics*; *Statistical and Biological Physics*.
- The Elective Area module is usually composed of two advanced modules or courses which can be chosen from other areas of the faculty for mathematics and natural sciences and/or a physical specialization not yet selected in the PAoS or SAoS,
- The topic for the Master Thesis usually will be chosen from the Primary Area of Specialization.

Thanks to the cooperation with the University of Bonn, students have further options at their disposal:

- If approved by the module coordinator, fitting courses from Bonn may be credited in the Areas of Specialization and the Elective Area as they are specified above.
- Students may also choose a lab course in *Particle Physics* from Bonn within one of the Practical Trainings.
- The SAoS might also be chosen from the following subjects offered in Bonn: *Cosmology*; *Experimental Hadron Physics*; *High Energy Particle Physics*; *Physics in Medicine*; *Quantum Optics and Optical Condensed Matter Physics*; *Theoretical Hadron Physics*; *Theoretical Particle Physics*.

The individual specializations are accompanied by different combinations of courses. It is not mandatory for students to decide at the beginning of their studies which of the offered specializations they would like to choose in each case. However, students should have decided by the end of the first semester at the latest in order to avoid a delay in the oral overview examinations at the end of the modules.

Further details on the modules are given in section 2.

1.3 CP Overview

The 120 CP of the Master studies split up into 66 CP for the lecture component, 24 CP for the Introductory Projects and 30 CP for the Master Thesis.

General CP Overview	
Lecture Component	66 CP
Introductory Projects	24 CP
Master Thesis	30 CP
Total	120 CP

1.4 CP Overview Corresponding to Semesters

The following table provides an overview of all modules. The first two columns indicate for which semester(s) the modules are planned for students starting either in the winter term or in the summer term.

CP Overview					
Semester (WiSe Start)	Semester (SuSe Start)	Module	CT	PW	CP
1 or 2	1 or 2	Advanced Theoretical Physics	84	186	9
1	1	Practical Training I	16	164	6
1 – 2	1 – 2	Primary Area of Specialization	540*		18
1– 2	1– 2	Second Area of Specialization	360*		12
1– 2	1– 2	Elective Area	360*		12
2 – 3	2 – 3	Practical Training II	46	224	9
3	3	Introductory Project I	360*		12
3	3	Introductory Project II	360*		12
4	4	Master Thesis	900*		30

* The distribution of the WL to CT and PW depends on the individual choice.

1.5 Calculation of the Overall Grade

The modules contribute to the overall grade according to their individual credit points. The Master Thesis has weight 1.5; the Introductory Projects have weight 0; all other modules have weight 1. The following table provides the weighted contributions of each module.

Significance of the module mark for the overall grade		
Module	CP	Contribution to the overall grade
Advanced Theoretical Physics	9	9/111
Practical Training I	6	6/111
Primary Area of Specialization	18	18/111
Second Area of Specialization	12	12/111
Elective Area	12	12/111
Practical Training II	9	9/111
Introductory Project I	12	0
Introductory Project II	12	0
Research Module Master Thesis	30	45/111

2 Descriptions and Tables of Modules

2.1 Core Modules

A course from the field of theoretical physics and the two modules Practical Training deepen the basic knowledge gained in the bachelor studies. The theoretical physics course may be chosen as either “Advanced Quantum Mechanics” or “Advanced Statistical Physics”.

Advanced Theoretical Physics – Advanced Quantum Mechanics

<table>
<tr><td colspan="8">Module Name: Advanced Theoretical Physics – Advanced Quantum Mechanics</td></tr>
<tr><td colspan="5">Type of Module
o Core Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="3">Module Code
AQM</td></tr>
<tr><td colspan="2">Identification Number
MN-P-AQM</td><td>Workload
270 h</td><td>Credit Points
9 CP</td><td>Term
1st or 2nd semester</td><td>Offered Every
Summer term</td><td>Start
Summer term</td><td>Duration
1 semester</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lecture
b) Problem Class</td><td colspan="2">Contact times
56 h
28 h</td><td colspan="3">Private Study
96 h
90 h</td></tr>
<tr><td>2</td><td colspan="7">Module Objectives and Skills to be Acquired
Building on the foundational exposition of quantum mechanics in the B. Sc. in Physics curriculum, this course teaches the parts of advanced quantum mechanics that are required knowledge for doing master thesis research in experimental or theoretical physics.
In particular, the course develops the basic formalism of quantum scattering theory, arguably the main tool to analyze fundamental physics experiments at high and low energies. The part on the Dirac equation, governing all fundamental matter fields, discusses the novel features that arise when quantum mechanics is combined with the theory of special relativity; here, students learn where 'spin' comes from, and they get an outlook on the origins of quantum field theory. The part on second quantization introduces the formalism needed for the many-body physics of atomic nuclei and condensed matter systems.
The lectures and exercises convey the required specialist knowledge and place high demands on the students' analytical thinking skills. In particular, the ability to abstract problems should also be deepend.
In addition to deepening the lecture material, the exercises also serve to train problem-solving strategies. An additional goal is the training of communication skills and presentation competence.</td></tr>
<tr><td>3</td><td colspan="7">Module Content
1. The formalism of second quantization
• construction of the Fock space for fermions and bosons
• second quantization of one- and two-body operators</td></tr>
</table>

	• vacuum state and normal ordering • quantum theory of the free electromagnetic field 2. Scattering theory • differential cross section • method of partial waves and scattering phases for systems with spherical symmetry • optical theorem, Lippmann-Schwinger equation, Born approximation • time-dependent scattering theory, Moeller operators • scattering matrix, multichannel scattering 3. Relativistic quantum theory • Dirac equation, invariance properties (parity, time reversal, charge conjugation) • hole interpretation of the positron, nonrelativistic reduction • Pauli equation, spinors 4. Specialized topic in advanced quantum mechanics, for example, applications of group theory (theory of angular momentum and spin), the standard model of particle physics, or quantum information theory. Literature: Sakurai, Modern Quantum Mechanics (Addison-Wesley) Schwabl, Advanced Quantum Mechanics (Springer)
4	Teaching Methods Lectures and problem classes
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Classical theoretical physics (mechanics and electrodynamics), basic quantum mechanics (as taught in a one-semester theoretical physics course on quantum mechanics).
6	Type of Examination At the beginning of the lecture-free period, there is a 120 to 180-minute written exam, the content of which is the material from the lecture and exercises. To be accepted for the written exam, students must actively participate in the problem classes and register for the exam. Before the beginning or at the beginning of the following semester, a retake exam is offered. The exam grade is the module grade. In the case of two passed examinations (cf. § 20 subparagraph 10 examination regulations), the better grade is the module grade.
7	Credits Awarded Successful completion of the exercises and the exam.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 9/111.
10	Module Coordinator David Gross
11	Further Information Version: 14.04.2023 DG, PN

Advanced Theoretical Physics – Advanced Statistical Physics

<table>
<tr><td colspan="8">Module Name: Advanced Theoretical Physics – Advanced Statistical Physics</td></tr>
<tr><td colspan="4">Type of Module
o Core Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="4">Module Code
ASP</td></tr>
<tr><td colspan="2">Identification Number

MN-P-ASP</td><td>Workload

270 h</td><td>Credit Points

9 CP</td><td>Term

1st or 2nd semester</td><td>Offered Every

Winter term</td><td>Start

Winter term</td><td>Duration

1 semester</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lecture
b) Problem Class</td><td colspan="2">Contact times
56 h
28 h</td><td colspan="3">Private Study
96 h
90 h</td></tr>
<tr><td>2</td><td colspan="7">Module Objectives and Skills to be Acquired
This course introduces a wide range of concepts used to describe interacting many-particle systems, such as stochastic dynamics in and out of equilibrium, exact solutions of lattice models, Landau theory and fluctuations, the renormalization group, and disordered systems.
In particular, the renormalization group provides a unifying language across a wide range of theoretical physics: from quantum field theory and particle physics to statistical physics and condensed matter. Stochastic dynamics is a key concept to describe systems out of equilibrium, for instance transport and traffic phenomena, the dynamics of biomolecules, neural systems, or biological evolution.
The lectures and exercises convey the required specialist knowledge and place high demands on the students' analytical thinking skills. In particular, the course fosters formulating and solving abstract models.
In addition to deepening the lecture material, the exercises also train problem-solving strategies. An additional goal is the teaching of communication skills and presentation competence.</td></tr>
<tr><td>3</td><td colspan="7">Module Content
1. Macroscopic and microscopic degrees of freedom
• conservation laws
• fast and slow variables
• elementary continuum mechanics and hydrodynamics
2. Phase transitions and critical phenomena
• Universality
• Landau theory
• relevance of fluctuations
• field-theoretic approach
3. Scaling and renormalization
4. Dynamics
• Correlation- and response functions
• Langevin- and Fokker-Planck equations
• the Wiener integral
• nonequilibrium stationary states
5. Disordered systems and glasses</td></tr>
</table>

	Literature: Plischke and Bergersen, Equilibrium statistical physics (World Scientific) Goldenfeld, Lectures on phase transitions and the renormalization group (Westview Press) Kardar, Statistical Physics of Fields (Cambridge University Press)
4	Teaching Methods Lectures and problem classes
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Classical theoretical physics, elementary thermodynamics and statistical physics.
6	Type of Examination At the beginning of the lecture-free period, there is a 120 to 180-minute written exam, the content of which is the material from the lecture and exercises. To be accepted for the written exam, students must actively participate in the problem classes and register for the exam. Before the beginning or at the beginning of the following semester, a retake exam is offered. The exam grade is the module grade. In the case of two passed examinations (cf. § 20 Paragraph 10 Examination Regulations), the better grade is the module grade.
7	Credits Awarded Successful completion of the exercises and the exam.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 9/111.
10	Module Coordinator Johannes Berg
11	Further Information The course is a recommended prerequisite for the area of specialization "Statistical and Biological Physics". Version: 11.04.2023 JB, PN

Practical Training I

Module Name: Practical Training I						
Type of Module o Core Module o Advanced Module o Specialisation Module o Supplementary Module			Module Code PractTr1			
Identification Number	Workload	Credit Points	Term	Offered Every	Start	Duration
MN-P-PractTr1	180 h	6 CP	1st semester	Every term	Every term	1 semester

1	Course Types	Contact times	Private Study
	a) Preparation for experiments	---	44 h
	b) Perform experiments	16 h	---
	c) Analysis and Report	---	120 h

2 Module Objectives and Skills to be Acquired

The course consists of advanced experiments introducing into important subfields of contemporary experimental physics. The students gain insight in relevant contemporary research by conducting experiments independently.

Students train to determine experimental quantities and their errors. They apply modern experimental physics methods as well computer aided analysis of scientific data. The written presentation of scientific results trains their scientific communication skills.

The module also trains social skills such as teamwork, the ability to take criticism, and time management.

3 Module Content

Advanced methods of performing physics experiments are introduced by setting up and conducting four experiments. The experiments introduce students to modern physics research. The experiments have to be selected from one category group out of atomic physics, condensed matter physics, nuclear physics, biophysics or computational physics.

The selected subfield of the experiments should be motivated and guided by the main focus of the selected master research fields.

4 Teaching Methods

After registration the participants will work in small subgroups of at most 3 students. Before carrying out an experiment, the student shall demonstrate to have acquired background knowledge for the experiments. For each experiment, the preparation, the measured results and the data analysis have to be documented in written form.

5 Prerequisites (for the Module)

Formal: Enrolment in the M. Sc. in Physics course in Cologne

In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics.

6 Type of Examination

The successful preparation, execution and evaluation of the experiments is certified without grades. All experiments must be passed, failed experiments can be repeated.

	After successful completion of the experiments, there is a 30-40 minute oral examination. A failed examination can be repeated. The grade of the oral examination is the module grade.
7	Credits Awarded Successful completion of all experiments and passing the oral examination.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 6/111.
10	Module Coordinators Frank Lewen, Thomas Lorenz, Berenike Maier, Peter Reiter, Simon Trebst
11	Further Information Alternatively to the categories listed above, experiments in particle physics may be performed in Bonn and credited in Cologne. In this case, the module examinations follow the regulations of Bonn University. Version: 10.04.2023 TL, ST, PN

Practical Training II

Module Name: Practical Training II						
Type of Module o Core Module o Advanced Module o Specialisation Module o Supplementary Module			Module Code PractTr2			
Identification Number	Workload	Credit Points	Term	Offered Every	Start	Duration
MN-P-PractTr2	270 h	9 CP	2nd to 3rd semester	Every term	Every term	2 semesters

1	Course Types	Contact times	Private Study
	a) Preparation for experiments	---	44 h
	b) Perform experiments	16 h	---
	c) Analysis and Report	---	120 h
	d) Seminar	30 h	60 h

2 Module Objectives and Skills to be Acquired

The first part of the module consists of advanced experiments introducing into important subfields of contemporary experimental physics. The students gain insight in relevant contemporary research by conducting experiments independently.

Students train to determine experimental quantities and their errors. They apply modern experimental physics methods as well computer aided analysis of scientific data. The written presentation of scientific results trains their scientific communication skills.

By preparing an advanced seminar, students become acquainted with a current topic of research, scientific methods and literature. They also learn to present an advanced research topic in oral form and to critically reflect scientific questions on a professional level. The mutual exchange about what has been presented trains the students in scientific discours.

In addition, the module also trains social skills such as teamwork, the ability to take criticism, and time management.

3 Module Content

Advanced methods of performing physics experiments are introduced by setting up and conducting four experiments. The experiments introduce students to modern physics research. The experiments have to be selected from one category group out of atomic physics, condensed matter physics, nuclear physics, biophysics or computational physics.

The selected subfield of the experiments should be motivated and guided by the main focus of the selected master research fields.

Additionally, students have to take part in an Advanced Seminar on a topic of current research. The selected subfield of the seminar should be motivated and guided by the choice of the Primary Area of Specialization.

4 Teaching Methods

After registration the participants will work in small subgroups of at most 3 students. Before carrying out an experiment, the student shall demonstrate to have acquired background knowledge for the experiments. For each experiment, the preparation, the measured results and the data analysis have to

	be documented in written form. By preparing an advanced seminar, students become acquainted with a current topic of research, scientific methods and literature. They also listen to and discuss the presentations of their fellow students.
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics.
6	Type of Examination The successful preparation, execution and evaluation of the experiments is certified without grades. All experiments must be passed, failed experiments can be repeated. After successful completion of the experiments, there is a 30-40 minute oral examination. A failed examination can be repeated. The grade of the oral examination is the module grade. The module is completed by the ungraded oral presentation in the Advanced Seminar.
7	Credits Awarded Successful completion of all experiments and passing the oral examination as well as the seminar presentation.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 9/111.
10	Module Coordinators Frank Lewen, Thomas Lorenz, Berenike Maier, Peter Reiter, Simon Trebst
11	Further Information Alternatively to the categories listed above, experiments in particle physics may be performed in Bonn and credited in Cologne. In this case, the module examinations follow the regulations of Bonn University. However, passing the Advanced Seminar is required for the award of the credits. Version: 14.04.2023 TL, ST, PN

2.2 Advanced Modules

n/a

2.3 Specialization Modules

The students focus on specific fields of physics from the first semester on by attending specialization modules. At the beginning, basic knowledge is gained on two subjects – the Primary and the Secondary Area of Specialization. In the second year, the students start with active research in the two Introductory Projects, preparing for the Master Thesis. Usually, students do their Introductory Projects and the Master Thesis in their Primary Area of Specialization.

Primary Area of Specialization Astrophysics

<table>
<tr><td colspan="8">Module Name: PAoS Astrophysics</td></tr>
<tr><td colspan="4">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="4">Module Code
PAoS Astro</td></tr>
<tr><td>Identification Number</td><td>Workload</td><td>Credit Points</td><td>Term</td><td>Offered Every</td><td>Start</td><td colspan="2">Duration</td></tr>
<tr><td>MN-P-PAoS-Astro</td><td>540 h</td><td>18 CP</td><td>1st to 2nd semester</td><td>Fitting courses offered every semester, for details see course offerings</td><td>Every term</td><td colspan="2">2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises
c) Seminar (optional)
d) Research internship (optional)</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="3">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="7">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge and specialize in astrophysics.
The students train
• to apply fundamental concepts of physics to describe astrophysical phenomena,
• to obtain an overview of the experimental foundations of our knowledge about the cosmos,
• to understand the fundamental principles of the universe and its history,
• to apply computer aided analysis of scientific data,
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses and the exam in a timely manner.
The module prepares students for topics of current research in astrophysics and towards their own research activity within the master thesis.</td></tr>
</table>

3	Module Content The module is subdivided into a core courses, specialized courses, an advanced seminar and a research internship. 1. Core course • Advanced Astrophysics (4+2 HPW, 9 CP): Interstellar medium, star formation, galaxies, cosmology – offered every winter term 2. Specialized courses, offered with variable frequency – specified annually in the course offerings • Active Galaxies (2 HPW, 3 CP) • Astrochemistry (2 HPW, 3 CP) • Experimental Methods in Astrophysics (2 HPW, 3 CP) • Galaxy Dynamics (2 HPW, 3 CP) • Hydrodynamics (2 HPW, 3 CP) • Nuclear Astrophysics (2 HPW, 3 CP) • The Physics of the Interstellar Medium (2 HPW, 3 CP) • Star Formation (2 HPW, 3 CP) • Optical/Infrared Interferometry (2 HPW, 3 CP) • and others including fitting courses from the University of Bonn, if approved by the module coordinator All specialized courses can be offered with additional exercises (2+1 HPW, 4.5 CP). 3. Advanced seminar on topical subjects of astrophysics (2 HPW, 3 CP) 4. Research internship (3 CP) Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes, seminar (optional), research internship (guidance to independent research; optional)
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Atomic physics and quantum mechanics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the problem classes of the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Primary Area of Specialization Astrophysics: 1. The core course Advanced Astrophysics (lectures and exercises) 2. Specialized courses to sum up to 18 CP. One specialized course of 3 CP can be replaced by a research internship provided that the scope of the internship is at least 4 weeks with 20 hours per week. Additionally, a specialized course of 3 CP can be replaced by an advanced seminar in astrophysics. Exercises for the core course as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.

8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 18/111.
10	Module Coordinator Peter Schilke
11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 16.04.2023 PS, PN

Primary Area of Specialization Condensed Matter Physics

Module Name: PAoS Condensed Matter Physics						
Type of Module o Basic Module o Advanced Module o Specialisation Module o Supplementary Module			Module Code PAoS CondMat			
Identification Number	Workload	Credit Points	Term	Offered Every	Start	Duration
MN-P-PAoS-CondMat	540 h	18 CP	1st to 2nd semester	Fitting courses offered every semester, for details see course offerings	Every term	2 semesters

1	Course Types a) Lectures b) Problem classes / exercises c) Seminar (optional) d) Research internship (optional)	Contact times depending on the individual choice	Private Study depending on the individual choice
2	Module Objectives and Skills to be Acquired In this module, students deepen previous knowledge and specialize in condensed matter physics. The students train • their understanding and knowledge of the main concepts (experimental & theoretical) of condensed matter physics, • to get familiar with some important experimental methods in condensed matter physics, • to apply the main concepts to selected up-to-date research topics of experimental condensed matter physics, • to solve challenging problems and to summarize and present acquired knowledge, • their self and time management skills by organizing their courses and the exam in a timely manner. The module prepares students for topics of current research in condensed matter physics and towards their own research activity within the master thesis.		
3	Module Content The module is subdivided into core courses, specialized courses, an advanced seminar, and a research internship. 1. Core courses • Condensed Matter Physics I (3+1 HPW, 6 CP): Crystal structure and binding, Reciprocal space, Lattice dynamics and thermal properties, Free electron gas – offered every winter term • Condensed Matter Physics II (3+1 HPW, 6 CP): Band structure, Metals and semiconductors, Transport properties, Dielectric function and screening, Superconductivity, Magnetism – offered every summer term 2. Specialized courses, at least one offered every year – specified annually in the course offerings		

	• Experimental Methods of Condensed Matter Physics (2 HPW, 3 CP) • Superconductivity and Nanoscience (2 HPW, 3 CP) • Magnetism (2 HPW, 3 CP) • Topological Matter (2 HPW, 3 CP) • Photons and Matter (2 HPW, 3 CP) • Physics of Surfaces and Nanostructures (2 HPW, 3 CP) • Introduction to Neutron Scattering (2 HPW, 3 CP) • Optical Spectroscopy (2 HPW, 3 CP) • Quantum Electronics and Qubits (2 HPW, 3 CP; 3+1 HPW, 6 CP resp.) • and others including fitting courses from the University of Bonn, if approved by the module coordinator 3. Advanced seminar on topical subjects of condensed matter physics (2 HPW, 3 CP) 4. Research internship (3 CP) Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes, seminar (optional), research internship (guidance to independent research; optional)
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the problem classes of the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Primary Area of Specialization Condensed Matter Physics: 1. The two core courses Condensed Matter Physics I and II (lectures and exercises) 2. Specialized courses to sum up to 18 CP. One specialized course of 3 CP can be replaced by a research internship provided that the scope of the internship is at least 4 weeks with 20 hours per week. Additionally, a specialized course of 3 CP can be replaced by an advanced seminar in condensed matter physics. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 18/111.
10	Module Coordinator Joachim Hemberger

11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 15.04.2023 JH, PN

Primary Area of Specialization Foundations of Quantum Technologies: Matter, Light and Information

<table>
<tr><td colspan="8">Module Name: PAoS Foundations of Quantum Technologies: Matter, Light and Information</td></tr>
<tr><td colspan="4">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="4">Module Code
PAoS QT</td></tr>
<tr><td>Identification Number</td><td>Workload</td><td>Credit Points</td><td>Term</td><td>Offered Every</td><td>Start</td><td colspan="2">Duration</td></tr>
<tr><td>MN-P-PAoS-QT</td><td>540 h</td><td>18 CP</td><td>1st to 2nd semester</td><td>Fitting courses offered every semester, for details see course offerings</td><td>Every term</td><td colspan="2">2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises
c) Seminar (optional)
d) Research internship (optional)</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="3">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="7">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge, learn the basics of quantum technologies and specialize in one or more areas (matter, light and/or information).
The students train
• to understand fundamental concepts of quantum technologies and information,
• to describe physical (matter- or light-based) platforms relevant to quantum technologies,
• to understand the benefits and challenges of conventional and topological quantum technologies,
• to translate theoretical concepts of quantum information into their physical realizations,
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses and the exam in a timely manner.
The module prepares students for topics of current research in quantum technology and towards their own research activity within the master thesis.</td></tr>
<tr><td>3</td><td colspan="7">Module Content
The module is subdivided into core courses, specialized courses, an advanced seminar and a research internship.
1. Core courses
• Quantum Information Theory (3+1 HPW, 6 CP): Structure of quantum mechanics, quantum teleportation, finite-dimensional quantum systems, entanglement; quantum information, introduction to information theory, quantum communication theory, quantum key distribution; quantum computation, Grover's algorithm – offered every winter term
• Quantum Electronics and Qubits (3+1 HPW, 6 CP): Landauer-Büttiker formalism in quantum</td></tr>
</table>

	transport, localization corrections, Quantum Hall effect(s), van der Waals materials, quantum dots and spin qubits, cavity quantum electrodynamics and superconducting qubits – offered every summer term • Quantum Optics (3+1 HPW, 6 CP): Imported course from the University of Bonn (https://web3.physik.uni-bonn.de/mhb/mhb.php?stg=MSPHYSIK2&modulteil=physics631) – offered every winter term 2. Specialized courses, at least one offered every year – specified annually in the course offerings • Computational Many-Body Physics (3+1 HPW, 6 CP) • Topological Matter (and Quantum Computing) (2 HPW, 3 CP) • Photons and Matter (2 HPW, 3 CP) • Platforms for Quantum Technologies (2 HPW, 3 CP) • Selected Topics in Quantum Technologies (3+1 HPW, 6 CP) • and others including further fitting courses from the University of Bonn or the University of Aachen, if approved by the module coordinator 3. Advanced Seminar on topical subjects of Quantum Technologies (2 HPW, 3 CP) 4. Research internship (3 CP) Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes, seminar (optional), research internship (guidance to independent research; optional)
5	Prerequisites (for the Module) Formal: Enrolment in the MSc in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the problem classes of the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Primary Area of Specialization Foundations of Quantum Technologies: Matter, Light and Information: 1. Two of the core courses (lectures and exercises) 2. A further core course or specialized courses to sum up to 18 CP. One specialized course of 3 CP can be replaced by a research internship provided that the scope of the internship is at least 4 weeks with 20 hours per week. Additionally, a specialized course of 3 CP can be replaced by an advanced seminar on a topic fitting with quantum technologies. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 18/111.

10	Module Coordinator Erwann Bocquillon
11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 13.04.2023 EB, PN

Primary Area of Specialization Molecular Physics

<table>
<tr><td colspan="7">Module Name: PAoS Molecular Physics</td></tr>
<tr><td colspan="4">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="3">Module Code
PAoS Mol</td></tr>
<tr><td>Identification Number</td><td>Workload</td><td>Credit Points</td><td>Term</td><td>Offered Every</td><td>Start</td><td>Duration</td></tr>
<tr><td>MN-P-PAoS-Mol</td><td>540 h</td><td>18 CP</td><td>1st to 2nd semester</td><td>Fitting courses offered every semester, for details see course offerings</td><td>Every term</td><td>2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises
c) Seminar (optional)
d) Research internship (optional)</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="2">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="6">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge and specialize in molecular physics.
The students train
• to understand the main concepts of molecular physics,
• to apply molecular physics concepts to current research in fundamental physics, atmospheric physics and astrophysics,
• to apply computer aided analysis of scientific data (e.g. molecular spectra),
• advanced experimental skills,
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses and the exam in a timely manner.
The module prepares students for topics of current research in molecular physics and towards their own research activity within the master thesis.</td></tr>
<tr><td>3</td><td colspan="6">Module Content
The module is subdivided into core courses, specialized courses, an advanced seminar and a research internship.
1. Core courses
• Molecular Physics I (3+1 HPW, 6 CP): Basics of Molecular Spectroscopy, Interaction of Radiation with Matter, Chemical Bond, Born-Oppenheimer-Approximation, Rigid Rotor, Harmonic Oscillator, Electronic States, Rotational Spectroscopy, Group Theory – offered every winter term
• Molecular Physics II (3+1 HPW, 6 CP): Rotational Spectroscopy, Vibrational Spectroscopy, Group Theory, Coupling of Rotation and Vibration, Transitions and Selection Rules, Nuclear</td></tr>
</table>

	Spin Statistics, Coupling of Angular Momenta, Hund`s Cases, Fine Structure (FS), HFS – offered every summer term 2. Specialized courses, offered with variable frequency – specified annually in the course offerings • Astrochemistry (2 HPW, 3 CP) • Introduction to Atmospheric Physics (2 HPW, 3 CP) • Measurement Techniques in Atmospheric Physics (2 HPW, 3 CP) • Experimental Methods in Astrophysics (2 HPW, 3 CP) • The Physics of the Interstellar Medium (2 HPW, 3 CP) • Star Formation (2 HPW, 3 CP) • and others including fitting courses from the University of Bonn, if approved by the module coordinator All specialized courses can be offered with additional exercises (2+1 HPW, 4.5 CP). 3. Advanced Seminar on topical subjects of molecular physics (2 HPW, 3 CP) 4. Research internship (3 CP) Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes, seminar (optional), research internship (guidance to independent research; optional)
5	Prerequisites (for the Module) Formal: Enrolment in the MSc in Physics course in Cologne In terms of content: Atomic physics and quantum mechanics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the problem classes of the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Primary Area of Specialization Molecular Physics: 1. The two core courses Molecular Physics I and II (lectures and exercises) 2. Specialized courses to sum up to 18 CP. One specialized course of 3 CP can be replaced by a research internship provided that the scope of the internship is at least 4 weeks with 20 hours per week. Additionally, a specialized course of 3 CP can be replaced by an advanced seminar in molecular physics. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M.Sc. programs.
9	Proportion of Final Grade The weight of the module is 18/111.
10	Module Coordinator Stephan Schlemmer

11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 16.04.2023 SS, PN

Primary Area of Specialization Nuclear and Particle Physics

Module Name: PAoS Nuclear Physics						
Type of Module o Basic Module o Advanced Module o Specialisation Module o Supplementary Module			Module Code PAoS Nuc			
Identification Number	Workload	Credit Points	Term	Offered Every	Start	Duration
MN-P-PAoS-Nuc	540 h	18 CP	1st to 2nd semester	Fitting courses offered every semester, for details see course offerings	Every term	2 semesters
1	Course Types a) Lectures b) Problem classes / exercises c) advanced seminars (optional) c) Research internship (optional)		Contact times depending on the individual choice		Private Study depending on the individual choice	
2	Module Objectives and Skills to be Acquired In this module, students deepen previous knowledge and specialize in nuclear physics. The students train • to understand the main concepts of nuclear and particle physics, including reaction theory and the physical principles of detectors and accelerators used in nuclear and particle physics, • advanced experimental skills, • to apply computer aided analysis of scientific data, • to solve challenging problems and to summarize and present acquired knowledge, • self and time management skills by organizing their courses and the exam in a timely manner. The module prepares students for topics of current research in nuclear physics and towards their own research activity within the master thesis.						
3	Module Content The module is subdivided into core courses, specialized courses, optional an advanced seminar and a optional research internship. 1. Core courses • Advanced Nuclear Physics (3+1 HPW, 6 CP): Study of nuclear structure and reactions – offered every winter term • Detectors for Nuclear and Particle Physics (3+1 HPW, 6 CP): Interaction of radiation with matter, detectors for charged and neutral particle. Exercises can be hands-on exercises in instrumentation. – offered every summer term 2. Specialized courses, at least one offered every term, specified every term in the course offerings. • Particle Physics (2 HPW, 3 CP)						

	• Theoretical Nuclear Physics I (2 HPW, 3 CP) • Theoretical Nuclear Physics II (2 HPW, 3 CP) • Theoretical Nuclear Physics III (2 HPW, 3 CP) • Accelerator Mass Spectrometry (2 HPW, 3 CP) • Nuclear Astrophysics (2 HPW, 3 CP) • Neutron Physics (2 HPW, 3 CP) • Selected problems in Nuclear Structure (2 HPW, 3 CP) • Selected Topics on Future Energy Supply (2 HPW, 3 CP) • Applied Nuclear Physics (2 HPW, 3 CP) • and other courses including courses from the University of Bonn, if approved by the module coordinator 3. Advanced Seminar on topical subjects of nuclear physics (2 HPW, 3 CP) 4. Research internship (3 CP) Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes, seminar (optional), research internship (optional)
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Nuclear and particle physics as well as quantum mechanics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Primary Area of Specialization Nuclear Physics: 1. The two core courses Advanced Nuclear Physics and Detectors for Nuclear and Particle Physics (lectures and exercises) 2. Specialized courses to sum up to 18 CP. One specialized course of 3 CP can be replaced by a research internship. The internship is at least 4 weeks with 20 hours per week. One specialized course of 3 CP can be replaced by an advanced seminar in nuclear physics. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 18/111.
10	Module Coordinator Peter Reiter

11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 12.04.2023 PR, PN

Primary Area of Specialization Quantum Field Theory / General Theory of Relativity

Module Name: PAoS Quantum Field Theory / General Theory of Relativity						
Type of Module o Basic Module o Advanced Module o Specialisation Module o Supplementary Module			Module Code PAoS QFT-GR			
Identification Number	Workload	Credit Points	Term	Offered Every	Start	Duration
MN-P-PAoS-QFT-GR	540 h	18 CP	1st to 2nd semester	Fitting courses offered every semester, for details see course offerings	Every term	2 semesters
1	Course Types a) Lectures b) Problem classes / exercises c) Seminar (optional) d) Research internship (optional)		Contact times depending on the individual choice		Private Study depending on the individual choice	
2	Module Objectives and Skills to be Acquired In this module, students deepen previous knowledge and specialize in quantum field theory and/or general relativity. The students train • to master the fundamental concepts of quantum field theory and/or general relativity, • to apply the basic concepts to investigate and predict the behavior of simple systems, • to work on and solve simple model problems independently and justify their approach, • interdisciplinary skills through the expanded range of subjects including related topics in neighboring areas such as astrophysics, particle physics and physics-related mathematics eligible as specialized courses, • to solve challenging problems and to summarize and present acquired knowledge, • their self and time management skills by organizing their courses and the exam in a timely manner. The module prepares students for topics of current research in quantum field theory and/or general relativity and towards their own research activity within the master thesis.						
3	Module Content The module is subdivided into core courses, specialized courses, an advanced seminar and a research internship. 1. Core courses • Quantum Field Theory I (4+2 HPW, 9 CP): second quantization, functional integrals, perturbation theory, applications in many body physics – offered every winter term • Quantum Field Theory II (4+2 HPW, 9 CP): spontaneous symmetry breaking, renormalization group theory, advanced topics in quantum field theory – offered every summer term					

	• General Relativity (4+2 HPW, 9 CP): geometric framework, principles of GR and Einstein's equations, simple solutions e.g. Schwarzschild solution and gravitational waves – offered every winter term 2. Specialized courses, at least one offered every year – specified annually in the course offerings • Geometry in Physics (4+2 HPW, 9 CP), • Introduction to Holography (4+2 HPW, 9 CP) • Quantum Information Theory (3+1 HPW, 6 CP) In order to increase the number of course offers and to deepen the students' understanding of the concepts and methods, specialized courses from neighboring fields of physics can also be selected (see list below). These courses can only be included with a maximum of 6 credit points. • Particle- and Astrophysics: Advanced Astrophysics as well as Theoretical Particle Physics, Theoretical Particle Astrophysics, Advanced Theoretical Particle Physics and/or Superstring Theory from the University of Bonn • Physics-related Mathematics: Topology, Differential Geometry, Group Theory, Functional Analysis, Complex Geometry • and others including further fitting courses from the University of Bonn, if approved by the module coordinator 3. Advanced Seminar on topical subjects of quantum field theory and/or general relativity (2 HPW, 3 CP) 4. Research internship (3 CP) Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes, seminar (optional), research internship (guidance to independent research; optional)
5	Prerequisites (for the Module) Formal: Enrolment in the MSc in Physics course in Cologne In terms of content: Theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses, including the seminar and research internships if applicable. To be admitted to the exam, students must actively participate in the problem classes of the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Primary Area of Specialization Quantum Field Theory / General Theory of Relativity: 1. At least one core course (lectures and exercises) 2. A further core course or specialized courses to sum up to 18 CP. One specialized course of 3 CP can be replaced by a research internship provided that the scope of the internship is at least 4 weeks with 20 hours per week. Additionally, a specialized course of 3 CP can be replaced by an advanced seminar in quantum field theory and/or general relativity. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.

8	Compatibility with other Curricula As elective subject in other M.Sc. programs.
9	Proportion of Final Grade The weight of the module is 18/111.
10	Module Coordinator Nele Callebaut
11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 15.04.2023 NC, PN

Primary Area of Specialization Solid State Theory / Computational Physics

<table>
<tr><td colspan="7">Module Name: PAoS Solid State Theory / Computational Physics</td></tr>
<tr><td colspan="4">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="3">Module Code
PAoS ThSol</td></tr>
<tr><td>Identification Number</td><td>Workload</td><td>Credit Points</td><td>Term</td><td>Offered Every</td><td>Start</td><td>Duration</td></tr>
<tr><td>MN-P-PAoS-ThSol</td><td>540 h</td><td>18 CP</td><td>1st to 2nd semester</td><td>Fitting courses offered every semester, for details see course offerings</td><td>Every term</td><td>2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises
c) Seminar (optional)
d) Research internship (optional)</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="2">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="6">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge and specialize in solid state theory and computational physics.
The students train
• to understand fundamental concepts used to theoretically describe solids and their excitations,
• to describe phenomena like superconductivity and magnetism,
• to understand important quantum field-theoretical and computational methods,
• to translate mathematical concepts into algorithms and apply them to many-body physics,
• to link concepts from quantum information theory, computational physics and solid state physics
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses and the exam in a timely manner.
The module prepares students for topics of current research in solid state theory and computational physics and towards their own research activity within the master thesis.</td></tr>
<tr><td>3</td><td colspan="6">Module Content
The module is subdivided into core courses, specialized courses, an advanced seminar and a research internship.
1. Core courses
• Solid State Theory (3+1 HPW, 6 CP): Concepts of solid state theory and description of excitations in solid – offered in the winter term 23/24 and every summer term starting from 2025
• Computational Many-Body Physics (3+1 HPW, 6 CP): Overview of elementary numerical approaches to study many-body systems, both classical and quantum – offered in summer 2024</td></tr>
</table>

	and every winter term starting from 2024/2025 • Quantum Field Theory I (4+2 HPW, 9 CP): Modern methods to describe solids based on functional integrals and by using diagrammatic methods – offered every winter term 2. Specialized courses • Quantum Field Theory II (4+2 HPW, 9 CP) – offered every summer term • Quantum Information Theory (3+1 HPW, 6 CP) – offered in summer 24 and every winter term starting from 24/25 • Specialized courses in Solid State Theory – offered with variable frequency • One course chosen from the specialized courses of the module Condensed Matter Physics • and others including further fitting courses from the University of Bonn, if approved by the module coordinator 3. Advanced Seminar on topical subjects of Solid State Theory / Computational Physics (2 HPW, 3 CP) 4. Research internship (3 CP) Specialized courses can also be taught as block courses, e.g., in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes, seminar (optional), research internship (guidance to independent research; optional)
5	Prerequisites (for the Module) Formal: Enrolment in the MSc in Physics course in Cologne In terms of content: Theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses, including the seminar and research internships if applicable. To be admitted to the exam, students must actively participate in the problem classes of the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Primary Area of Specialization Solid State Theory / Computational Physics: 1. Two of the core courses or, alternatively, both the courses Quantum Field Theory I and Quantum Field Theory II (lectures and exercises) 2. A further core course or specialized courses to sum up to 18 CP. One specialized course of 3 CP can be replaced by a research internship provided that the scope of the internship is at least 4 weeks with 20 hours per week. Additionally, a specialized course of 3 CP can be replaced by an advanced seminar in solid state theory. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 18/111.

10	Module Coordinator Achim Rosch
11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 15.04.2023 AR, PN

Primary Area of Specialization Statistical and Biological Physics

Module Name: PAoS Statistical and Biological Physics						
Type of Module o Basic Module o Advanced Module o Specialisation Module o Supplementary Module			Module Code PAoS StatBio			
Identification Number	Workload	Credit Points	Term	Offered Every	Start	Duration
MN-P-PAoS-StatBio	540 h	18 CP	1st to 2nd semester	Fitting courses offered every semester, for details see course offerings	Every term	2 semesters
1	Course Types a) Lectures b) Problem classes / exercises c) Seminars (optional) d) Research internship (optional)		Contact times depending on the individual choice		Private Study depending on the individual choice	
2	Module Objectives and Skills to be Acquired In this module, students deepen previous knowledge and specialize in statistical and biological physics. The students train • to apply concepts from physics to biological systems, • to understand complex phenomena emerging from simple systems, • to construct models and infer model parameters from empirical observations, • interdisciplinary skills and interaction between experiment and theory, • to solve challenging problems and to summarize and present acquired knowledge, • their self and time management skills by organizing their courses and the exam in a timely manner. The module prepares students for topics of current research in statistical and biological physics and towards their own research activity within the master thesis.						
3	Module Content The module is subdivided into core courses, specialized courses, seminars and a research internship. 1. Core courses • Physics of Living Systems (3+1 HPW, 6 CP): Introduction to molecular cell biology, dynamical systems, dynamics of small gene regulatory networks, noise in gene expression, statistical analysis of large biological networks, biological pattern formation, reaction-diffusion systems – offered every winter term • Statistical Biology of Evolution (3+1 HPW, 6 CP): Basic concepts of evolutionary theory, introduction to molecular evolution and genomics, theory of bio-molecular networks, concepts and methods of data analysis – offered every summer term						

	• Selected Topics in Statistical Physics (3+1 HPW, 6 CP), including Soft and biological matter, Non-equilibrium statistical physics, Statistical physics of disordered systems, information, and inference – offered in loose succession but specified annually in the course offerings All core courses can be offered with an additional seminar (3+1+1 HPW, 7.5 CP). 2. Specialized courses, offered with variable frequency – specified annually in the course offerings • Experiment and Simulation on Biological Systems (3 HPW, 4.5 CP) • Probability theory and stochastic processes for Physicists (3+1 HPW, 6 CP) • Introduction to Network Science (2+2 HPW, 6 CP) • Living Matter Hackathon (3 HPW, 4.5 CP) • Immunology for Physicists (2 HPW, 3 CP) • Physics of Granular Matter (2+1 HPW, 4,5 CP) • and others including fitting courses from the University of Bonn, if approved by the module coordinator 3. Advanced Seminar in Statistical and Biological Physics (3 CP) 4. Research internship (3 CP) Specialized courses can also be taught as block courses, e.g., in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online
4	Teaching Methods Lectures, problem classes, seminar (optional), research internship (guidance to independent research; optional)
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the problem classes of the core courses (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Primary Area of Specialization Statistical and Biological Physics: 1. At least two core courses (lectures and exercises) 2. A further core course or specialized courses to sum up to 18 CP. One specialized course of 3 CP can be replaced by a research internship provided that the scope of the internship is at least 4 weeks with 20 hours per week. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 18/111.

10	Module Coordinator Berenike Maier
11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 20.06.2024 BM, PN

Secondary Area of Specialization Astrophysics

<table>
<tr><td colspan="7">Module Name: SAoS Astrophysics</td></tr>
<tr><td colspan="4">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="3">Module Code
SAoS Astro</td></tr>
<tr><td>Identification Number</td><td>Workload</td><td>Credit Points</td><td>Term</td><td>Offered Every</td><td>Start</td><td>Duration</td></tr>
<tr><td>MN-P-SAoS-Astro</td><td>360 h</td><td>12 CP</td><td>1st to 2nd semester</td><td>Fitting courses offered every semester, for details see course offerings</td><td>Every term</td><td>2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="2">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="6">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge and specialize in astrophysics.
The students train
• to apply fundamental concepts of physics to describe astrophysical phenomena,
• to obtain an overview of the experimental foundations of our knowledge about the cosmos,
• to understand the fundamental principles of the universe and its history,
• to apply computer aided analysis of scientific data,
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses and the exam in a timely manner.</td></tr>
<tr><td>3</td><td colspan="6">Module Content
The module is subdivided into a core courses and specialized courses.
1. Core course
• Advanced Astrophysics (4+2 HPW, 9 CP): Interstellar medium, star formation, galaxies, cosmology – offered every winter term
2. Specialized courses, offered with variable frequency – specified annually in the course offerings
• Active Galaxies (2 HPW, 3 CP)
• Astrochemistry (2 HPW, 3 CP)
• Experimental Methods in Astrophysics (2 HPW, 3 CP)
• Galaxy Dynamics (2 HPW, 3 CP)
• Hydrodynamics (2 HPW, 3 CP)
• Nuclear Astrophysics (2 HPW, 3 CP)
• The Physics of the Interstellar Medium (2 HPW, 3 CP)
• Star Formation (2 HPW, 3 CP)
• Optical/Infrared Interferometry (2 HPW, 3 CP)</td></tr>
</table>

	• and others including fitting courses from the University of Bonn, if approved by the module coordinator All specialized courses can be offered with additional exercises (2+1 HPW, 4.5 CP). Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Atomic physics and quantum mechanics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the problem classes of the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Secondary Area of Specialization Astrophysics: 1. The core course Advanced Astrophysics (lectures and exercises) 2. A specialized course to sum up to 12 CP. Exercises for the core course as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Peter Schilke
11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 16.04.2023 PS, PN

Secondary Area of Specialization Condensed Matter Physics

<table>
<tr><td colspan="8">Module Name: SAoS Condensed Matter Physics</td></tr>
<tr><td colspan="5">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="3">Module Code
SAoS CondMat</td></tr>
<tr><td>Identification Number</td><td>Workload</td><td>Credit Points</td><td>Term</td><td>Offered Every</td><td>Start</td><td colspan="2">Duration</td></tr>
<tr><td>MN-P-SAoS-CondMat</td><td>360 h</td><td>12 CP</td><td>1st to 2nd semester</td><td>Fitting courses offered every semester, for details see course offerings</td><td>Every term</td><td colspan="2">2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises
c) Seminar (optional)</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="3">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="7">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge and specialize in condensed matter physics.
The students train
• their understanding and knowledge of the main concepts (experimental & theoretical) of condensed matter physics,
• to get familiar with some important experimental methods in condensed matter physics,
• to apply the main concepts to selected up-to-date research topics of experimental condensed matter physics,
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses and the exam in a timely manner.</td></tr>
<tr><td>3</td><td colspan="7">Module Content
The module is subdivided into core courses, specialized courses, and an optional seminar.
1. Core courses
• Condensed Matter Physics I (3+1 HPW, 6 CP): Crystal structure and binding, Reciprocal space, Lattice dynamics and thermal properties, Free electron gas – offered every winter term
• Condensed Matter Physics II (3+1 HPW, 6 CP): Band structure, Metals and semiconductors, Transport properties, Dielectric function and screening, Superconductivity, Magnetism – offered every summer term
2. Specialized courses, at least one offered every year – specified annually in the course offerings
• Experimental Methods of Condensed Matter Physics (2 HPW, 3 CP)
• Superconductivity and Nanoscience (2 HPW, 3 CP)
• Magnetism (2 HPW, 3 CP)
• Topological Matter (2 HPW, 3 CP)</td></tr>
</table>

	• Photons and Matter (2 HPW, 3 CP) • Physics of Surfaces and Nanostructures (2 HPW, 3 CP) • Introduction to Neutron Scattering (2 HPW, 3 CP) • Optical Spectroscopy (2 HPW, 3 CP) • Quantum Electronics and Qubits (2 HPW, 3 CP; 3+1 HPW, 6 CP resp.) • and others including fitting courses from the University of Bonn, if approved by the module coordinator Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes, seminar (optional)
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the problem classes of the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Secondary Area of Specialization Condensed Matter Physics: 1. The core course Condensed Matter Physics I (lectures and exercises) 2. The other core course or specialized courses to sum up to 12 CP. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Joachim Hemberger
11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 15.04.2023 JH, PN

Secondary Area of Specialization Foundations of Quantum Technologies: Matter, Light and Information

<table>
<tr><td colspan="7">Module Name: SAoS Foundations of Quantum Technologies: Matter, Light and Information</td></tr>
<tr><td colspan="4">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="3">Module Code
SAoS QT</td></tr>
<tr><td>Identification Number</td><td>Workload</td><td>Credit Points</td><td>Term</td><td>Offered Every</td><td>Start</td><td>Duration</td></tr>
<tr><td>MN-P-SAoS-QT</td><td>360 h</td><td>12 CP</td><td>1st to 2nd semester</td><td>Fitting courses offered every semester, for details see course offerings</td><td>Every term</td><td>2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="2">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="6">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge learn the basics of quantum technologies and specialize in one or more areas (matter, light and/or information).
The students train
• to understand fundamental concepts of quantum technologies and information,
• to describe physical (matter- or light-based) platforms relevant to quantum technologies,
• to understand the benefits and challenges of conventional and topological quantum technologies,
• to translate theoretical concepts of quantum information into their physical realizations,
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses and the exam in a timely manner.</td></tr>
<tr><td>3</td><td colspan="6">Module Content
The module is subdivided into core courses and specialized courses.
1. Core courses
• Quantum Information Theory (3+1 HPW, 6 CP): Structure of quantum mechanics, quantum teleportation, finite-dimensional quantum systems, entanglement; quantum information, introduction to information theory, quantum communication theory, quantum key distribution; quantum computation, Grover's algorithm – offered every winter term
• Quantum Electronics and Qubits (3+1 HPW, 6 CP): Landauer-Büttiker formalism in quantum transport, localization corrections, Quantum Hall effect(s), van der Waals materials, quantum dots and spin qubits, cavity quantum electrodynamics and superconducting qubits – offered every summer term
• Quantum Optics (3+1 HPW, 6 CP): Imported course from the University of Bonn (https://web3.physik.uni-bonn.de/mhb/mhb.php?stg=MSPHYSIK2&modulteil=physics631) – offered every winter term</td></tr>
</table>

	2. Specialized courses, at least one offered every year – specified annually in the course offerings • Computational Many-Body Physics (3+1 HPW, 6 CP) • Topological Matter (and Quantum Computing) (2 HPW, 3 CP) • Photons and Matter (2 HPW, 3 CP) • Platforms for Quantum Technologies (2 HPW, 3 CP) • Selected Topics in Quantum Technologies (3+1 HPW, 6 CP) • and others including further fitting courses from the University of Bonn or the University of Aachen, if approved by the module coordinator Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes
5	Prerequisites (for the Module) Formal: Enrolment in the MSc in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the problem classes of the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Secondary Area of Specialization Foundations of Quantum Technologies: Matter, Light and Information: 1. At least one core course (lectures and exercises) 2. A further core course or specialized courses to sum up to 12 CP. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Erwann Bocquillon
11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 05.04.2023 EB, PN

Secondary Area of Specialization Molecular Physics

<table>
<tr><td colspan="8">Module Name: SAoS Molecular Physics</td></tr>
<tr><td colspan="4">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="4">Module Code
SAoS Mol</td></tr>
<tr><td>Identification Number</td><td>Workload</td><td>Credit Points</td><td>Term</td><td>Offered Every</td><td>Start</td><td colspan="2">Duration</td></tr>
<tr><td>MN-P-SAoS-Mol</td><td>360 h</td><td>12 CP</td><td>1st to 2nd semester</td><td>Fitting courses offered every semester, for details see course offerings</td><td>Every term</td><td colspan="2">2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="3">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="7">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge and specialize in molecular physics.
The students train
• to understand the main concepts of molecular physics,
• to apply molecular physics concepts to current research in fundamental physics, atmospheric physics and astrophysics,
• to apply computer aided analysis of scientific data (e.g. molecular spectra),
• advanced experimental skills,
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses and the exam in a timely manner.</td></tr>
<tr><td>3</td><td colspan="7">Module Content
The module is subdivided into core courses and specialized courses.
1. Core courses
• Molecular Physics I (3+1 HPW, 6 CP): Basics of Molecular Spectroscopy, Interaction of Radiation with Matter, Chemical Bond, Born-Oppenheimer-Approximation, Rigid Rotor, Harmonic Oscillator, Electronic States, Rotational Spectroscopy, Group Theory – offered every winter term
• Molecular Physics II (3+1 HPW, 6 CP): Rotational Spectroscopy, Vibrational Spectroscopy, Group Theory, Coupling of Rotation and Vibration, Transitions and Selection Rules, Nuclear Spin Statistics, Coupling of Angular Momenta, Hund`s Cases, Fine Structure (FS), HFS – offered every summer term
2. Specialized courses, offered with variable frequency – specified annually in the course offerings
• Astrochemistry (2 HPW, 3 CP)
• Introduction to Atmospheric Physics (2 HPW, 3 CP)</td></tr>
</table>

	• Measurement Techniques in Atmospheric Physics (2 HPW, 3 CP) • Experimental Methods in Astrophysics (2 HPW, 3 CP) • The Physics of the Interstellar Medium (2 HPW, 3 CP) • Star Formation (2 HPW, 3 CP) • and others including fitting courses from the University of Bonn, if approved by the module coordinator All specialized courses can be offered with additional exercises (2+1 HPW, 4.5 CP). Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Atomic Physics and Quantum Mechanics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the problem classes of the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Secondary Area of Specialization Molecular Physics: 1. The core courses Molecular Physics I (lectures and exercises) 2. The other core course or specialized courses to sum up to 12 CP. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator S. Schlemmer
11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 16.04.2023 SS, PN

Secondary Area of Specialization Nuclear and Particle Physics

<table>
<tr><td colspan="8">Module Name: SAoS Nuclear Physics</td></tr>
<tr><td colspan="4">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="4">Module Code
SAoS Nuc</td></tr>
<tr><td>Identification Number</td><td>Workload</td><td>Credit Points</td><td>Term</td><td>Offered Every</td><td>Start</td><td colspan="2">Duration</td></tr>
<tr><td>MN-P-SAoS-Nuc</td><td>360 h</td><td>12 CP</td><td>1st to 2nd semester</td><td>Fitting courses offered every semester, for details see course offerings</td><td>Every term</td><td colspan="2">2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="3">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="7">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge and specialize in nuclear physics.
The students train
• to understand the main concepts of nuclear and particle physics, including reaction theory and the physical principles of detectors and accelerators used in nuclear and particle physics,
• advanced experimental skills,
• to apply computer aided analysis of scientific data,
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses and the exam in a timely manner.</td></tr>
<tr><td>3</td><td colspan="7">Module Content
The module is subdivided into core courses and specialized courses.
1. Core courses
• Advanced Nuclear Physics (3+1 HPW, 6 CP): Study of nuclear structure and reactions,– offered every winter term
• Detectors for Nuclear and Particle Physics (3+1 HPW, 6 CP): Interaction of radiation with matter, detectors for charged and neutral particle. Exercises can be hands-on exercises in instrumentation. – offered every summer term
2. Specialized courses at least one offered every term, specified every term in the course offerings.
• Particle Physics (2 HPW, 3 CP)
• Theoretical Nuclear Physics I (2 HPW, 3 CP)
• Theoretical Nuclear Physics II (2 HPW, 3 CP)
• Theoretical Nuclear Physics III (2 HPW, 3 CP)
• Accelerator Mass Spectrometry (2 HPW, 3 CP)</td></tr>
</table>

	• Nuclear Astrophysics (2 HPW, 3 CP) • Neutron Physics (2 HPW, 3 CP) • Selected problems in Nuclear Structure (2 HPW, 3 CP) • Selected Topics on Future Energy Supply (2 HPW, 3 CP) • Applied Nuclear Physics (2 HPW, 3 CP) • and other courses including courses from the University of Bonn, if approved by the module coordinator Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Nuclear and particle physics as well as quantum mechanics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the problem classes of the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Secondary Area of Specialization Nuclear Physics: 1. At least one core course (lectures and exercises) 2. The other core course or specialized courses to sum up to 12 CP. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Peter Reiter
11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 12.04.2023 PR, PN

Secondary Area of Specialization Quantum Field Theory / General Theory of Relativity

Module Name: SAoS Quantum Field Theory / General Theory of Relativity						
Type of Module o Basic Module o Advanced Module o Specialisation Module o Supplementary Module			Module Code SAoS QFT-GR			
Identification Number	Workload	Credit Points	Term	Offered Every	Start	Duration
MN-P-SAoS-QFT-GR	360 h	12 CP	1st to 2nd semester	Fitting courses offered every semester, for details see course offerings	Every term	2 semesters
1	Course Types a) Lectures b) Problem classes / exercises		Contact times depending on the individual choice		Private Study depending on the individual choice	
2	Module Objectives and Skills to be Acquired In this module, students deepen previous knowledge and specialize in quantum field theory and/or general relativity. The students train • to master the fundamental concepts of quantum field theory and/or general relativity, • to apply the basic concepts to investigate and predict the behavior of simple systems, • to work on and solve simple model problems independently and justify their approach, • interdisciplinary skills through the expanded range of subjects including related topics in neighboring areas such as astrophysics, particle physics and physics-related mathematics eligible as specialized courses, • to solve challenging problems and to summarize and present acquired knowledge, • their self and time management skills by organizing their courses and the exam in a timely manner.						
3	Module Content The module is subdivided into core courses and specialized courses. 1. Core courses • Quantum Field Theory I (4+2 HPW, 9 CP): second quantization, functional integrals, perturbation theory, applications in many body physics – offered every winter term • Quantum Field Theory II (4+2 HPW, 9 CP): spontaneous symmetry breaking, renormalization group theory, advanced topics in quantum field theory – offered every summer term • General Relativity (4+2 HPW, 9 CP): geometric framework, principles of GR and Einstein's equations, simple solutions e.g. Schwarzschild solution and gravitational waves – offered every winter term 2. Specialized courses, at least one offered every year – specified annually in the course offerings • Geometry in Physics (4+2 HPW, 9 CP),						

	• Introduction to Holography (4+2 HPW, 9 CP), • Quantum Information Theory (3+1 HPW, 6 CP) In order to increase the number of course offers and to deepen the students' understanding of the concepts and methods, specialized courses from neighboring fields of physics can also be selected (see list below). These courses can only be included with a maximum of 6 credit points. • Particle- and Astrophysics: Advanced Astrophysics as well as Theoretical Particle Physics, Theoretical Particle Astrophysics, Advanced Theoretical Particle Physics and/or Superstring Theory from the University of Bonn • Physics-related Mathematics: Topology, Differential Geometry, Group Theory, Functional Analysis, Complex Geometry • and others including further fitting courses from the University of Bonn, if approved by the module coordinator Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes
5	Prerequisites (for the Module) Formal: Enrolment in the MSc in Physics course in Cologne In terms of content: Theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the problem classes of the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Secondary Area of Specialization Quantum Field Theory / General Theory of Relativity: 1. At least one core course (lectures and exercises) 2. A further core course or specialized courses to sum up to 12 CP. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Nele Callebaut
11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 15.04.2023 NC, PN

Secondary Area of Specialization Solid State Theory / Computational Physics

<table>
<tr><td colspan="8">Module Name: SAoS Solid State Theory / Computational Physics</td></tr>
<tr><td colspan="4">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="4">Module Code
SAoS ThSol</td></tr>
<tr><td>Identification Number

MN-P-SAoS-ThSol</td><td>Workload

360 h</td><td>Credit Points

12 CP</td><td>Term

1st to 2nd semester</td><td>Offered Every

Fitting courses offered every semester, for details see course offerings</td><td>Start

Every term</td><td colspan="2">Duration

2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="3">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="7">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge and specialize in solid state theory and computational physics.
The students train
• to understand fundamental concepts used to theoretically describe solids and their excitations,
• to describe phenomena like superconductivity and magnetism,
• to understand important quantum field-theoretical and computational methods,
• to translate mathematical concepts into algorithms and apply them to many-body physics,
• to link concepts from quantum information theory, computational physics and solid state physics
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses and the exam in a timely manner.</td></tr>
<tr><td>3</td><td colspan="7">Module Content
The module is subdivided into core courses and specialized courses.
1. Core courses
• Solid State Theory (3+1 HPW, 6 CP): Concepts of solid state theory and description of excitations in solid – offered in the winter term 23/24 and every summer term starting from 2025
• Computational Many-Body Physics (3+1 HPW, 6 CP): Overview of elementary numerical approaches to study many-body systems, both classical and quantum – offered in summer 2024 and every winter term starting from 2024/2025
• Quantum Field Theory I (4+2 HPW, 9 CP): Modern methods to describe solids based on functional integrals and by using diagrammatic methods – offered every winter term
2. Specialized courses
• Quantum Field Theory II (4+2 HPW, 9 CP) – offered every summer term
• Quantum Information Theory (3+1 HPW, 6 CP) – offered in summer 24 and every winter term</td></tr>
</table>

	starting from 24/25 • Specialized courses in Solid State Theory – offered with variable frequency • One course chosen from the specialized courses of the module Condensed Matter Physics • and others including further fitting courses from the University of Bonn, if approved by the module coordinator Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes
5	Prerequisites (for the Module) Formal: Enrolment in the MSc in Physics course in Cologne In terms of content: Theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the problem classes of the core course (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Secondary Area of Specialization Solid State Theory / Computational Physics: 1. At least one core course (lectures and exercises) 2. A further core course or specialized courses to sum up to 12 CP. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Achim Rosch
11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 15.04.2023 AR, PN

Secondary Area of Specialization Statistical and Biological Physics

Module Name: SAoS Statistical and Biological Physics						
Type of Module o Basic Module o Advanced Module o Specialisation Module o Supplementary Module			Module Code SAoS StatBio			
Identification Number	Workload	Credit Points	Term	Offered Every	Start	Duration
MN-P-SAoS-StatBio	360 h	12 CP	1st to 2nd semester	Fitting courses offered every semester, for details see course offerings	Every term	2 semesters
1	Course Types a) Lectures b) Problem classes / exercises c) Seminars (optional)		Contact times depending on the individual choice		Private Study depending on the individual choice	
2	Module Objectives and Skills to be Acquired In this module, students deepen previous knowledge and specialize in statistical and biological physics. The students train • to apply concepts from physics to biological systems, • to understand complex phenomena emerging from simple systems, • to construct models and infer model parameters from empirical observations, • interdisciplinary skills and interaction between experiment and theory, • to solve challenging problems and to summarize and present acquired knowledge, • their self and time management skills by organizing their courses and the exam in a timely manner.					
3	Module Content The module is subdivided into core courses, specialized courses and seminars. 1. Core courses • Physics of Living Systems (3+1 HPW, 6 CP): Introduction to molecular cell biology, dynamical systems, dynamics of small gene regulatory networks, noise in gene expression, statistical analysis of large biological networks, biological pattern formation, reaction-diffusion systems – offered every winter term • Statistical Biology of Evolution (3+1 HPW, 6 CP): Basic concepts of evolutionary theory, introduction to molecular evolution and genomics, theory of bio-molecular networks, concepts and methods of data analysis – offered every summer term • Selected Topics in Statistical Physics (3+1 HPW, 6 CP), including Soft and biological matter, Non-equilibrium statistical physics, Statistical physics of disordered systems, information, and inference – offered in loose succession but specified annually in the course offerings					

	All core courses can be offered with an additional seminar (3+1+1 HPW, 7.5 CP). 2. Specialized courses, offered with variable frequency – specified annually in the course offerings • Experiment and Simulation on Biological Systems (3 HPW, 4.5 CP) • Probability theory and stochastic processes for Physicists (3+1 HPW, 6 CP) • Introduction to Network Science (2+2 HPW, 6 CP) • Living Matter Hackathon (3 HPW, 4.5 CP) • Immunology for Physicists (2 HPW, 3 CP) • Physics of Granular Matter (2+1 HPW, 4,5 CP) • and others including fitting courses from the University of Bonn, if approved by the module coordinator Specialized courses can also be taught as block courses e.g. in the term break (Intensive Weeks). The contents of the courses can be found in the lecture descriptions online.
4	Teaching Methods Lectures, problem classes, seminar (optional)
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination The module examination is by oral exam covering the topics of all attended courses. To be admitted to the exam, students must actively participate in the problem classes of the core courses (as defined in the individual courses). The grade given for the module is equal to the grade of the oral examination.
7	Credits Awarded For the award of credit points, the following courses must be taken in the module Secondary Area of Specialization Statistical and Biological Physics: 1. At least one core course (lectures and exercises) 2. A further core course or specialized courses to sum up to 12 CP. Exercises for the core courses as well as the oral examination on the contents of the selected courses according to the above scheme must be passed.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Berenike Maier
11	Further Information Detailed information regarding the frequency and content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 20.06.2024 BM, PN

Secondary Area of Specialization Cosmology (U Bonn)

<table>
<tr><td colspan="8">Module Name: SAoS Cosmology</td></tr>
<tr><td colspan="4">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="4">Module Code
SAoS Cosmo</td></tr>
<tr><td>Identification Number

MN-P-SAoS-Cosmo</td><td>Workload

360 h</td><td>Credit Points

12 CP</td><td>Term

1st to 2nd semester</td><td>Offered Every

Fitting courses offered every semester, for details see course offerings</td><td>Start

Every term</td><td colspan="2">Duration

2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="3">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="7">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge and specialize in the field of cosmology.
The students train
• to acquire deep understanding of the basics of our world models and their consequences with a special focus on the formation of structures in the universe,
• to perceive the connections between the fundamental questions of cosmology and particle physics (dark matter and dark energy),
• to see the benefits and limits of the interplay between observations and theoretical modelling,
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses.</td></tr>
<tr><td>3</td><td colspan="7">Module Content
Lectures in the SAoS Cosmology can be chosen from the list given below. For introduction, the lecture Cosmology, astro812, is strongly recommended.
• astro812 Cosmology, 6 CP
• astro845 Observational Cosmology, 4 CP
• astro849 Multiwavelength Observations fo Galaxy Clusters, 4 CP
• astro852 Gravitational Lensing, 4 CP
• astro8503 Radio and X-Ray Observations of Dark Matter and Dark Energy, 4 CP
• astro859 The cosmic history of the intergalactic medium, 4 CP
• and others if approved by the module coordinator</td></tr>
<tr><td>4</td><td colspan="7">Teaching Methods
Lectures, problem classes</td></tr>
<tr><td>5</td><td colspan="7">Prerequisites (for the Module)</td></tr>
</table>

	Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination All courses for the module are imported from the MSc in Astrophysics course in Bonn. For all exams, the rules of the Department of Physics/Astronomy at the University of Bonn apply. The module grade results from the weighted arithmetic mean of the individual grades.
7	Credits Awarded For the award of credit points, a sufficient number of courses from the list above has to be taken to sum-up to 12 CP. Corresponding exercises as well as exams must be passed. All courses for the module are imported from the MSc in Astrophysics course in Bonn. For all exams. the rules of the Department of Physics/Astronomy at the University of Bonn apply.
8	Compatibility with other Curricula Not applicable – module imported from the University of Bonn.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Achim Rosch
11	Further Information Detailed information regarding possible combinations of courses and the content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 15.04.2023 AR, PN

Secondary Area of Specialization Experimental Hadron Physics (U Bonn)

<table>
<tr><td colspan="8">Module Name: SAoS Experimental Hadron Physics</td></tr>
<tr><td colspan="4">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="4">Module Code
SAoS ExHad</td></tr>
<tr><td>Identification Number</td><td>Workload</td><td>Credit Points</td><td>Term</td><td>Offered Every</td><td>Start</td><td colspan="2">Duration</td></tr>
<tr><td>MN-P-SAoS-ExHad</td><td>360 h</td><td>12 CP</td><td>1st to 2nd semester</td><td>Fitting courses offered every semester, for details see course offerings</td><td>Every term</td><td colspan="2">2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="3">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="7">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge and specialize in the field of experimental hadron physics.
The students train
• to acquire deep understanding of the fundamentals of particle physics, in particular concerning the Standard Model of particle physics and the structure of hadrons,
• to understand the many-body structure of hadrons and receive an introduction to the experimental phenomenology of hadron physics,
• to familiarize themselves with current methods and experiments on topical issues in hadron physics,
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses.</td></tr>
<tr><td>3</td><td colspan="7">Module Content
Lectures in the SAoS Experimental Hadron Physics can be chosen from the list given below. For introduction, the lecture Particle Physics, physics611, is strongly recommended.
• physics611 Particle Physics, 6 CP
• physics632 Physics of Hadrons, 6 CP
• physics618 Physics of Particle Detectors, 6 CP
• physics612 Accelerator Physics, 6 CP
• physics720 Physics with Antiprotons, 3 CP
• physics715 Experiments on the Structure of Hadrons, 4 CP
• physics721 Intensive Week: Advanced Topics in Hadron Physics, 4 CP
• and others if approved by the module coordinator</td></tr>
</table>

4	Teaching Methods Lectures, problem classes
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination All courses for the module are imported from the MSc in Physics course in Bonn. For all exams, the rules of the Department of Physics/Astronomy at the University of Bonn apply. The module grade results from the weighted arithmetic mean of the individual grades.
7	Credits Awarded For the award of credit points, a sufficient number of courses from the list above has to be taken to sum-up to 12 CP. Corresponding exercises as well as exams must be passed. All courses for the module are imported from the MSc in Physics course in Bonn. For all exams. the rules of the Department of Physics/Astronomy at the University of Bonn apply.
8	Compatibility with other Curricula Not applicable – module imported from the University of Bonn.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Achim Rosch
11	Further Information Detailed information regarding possible combinations of courses and the content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 15.04.2023 AR, PN

Secondary Area of Specialization High Energy Particle Physics (U Bonn)

<table>
<tr><td colspan="8">Module Name: SAoS High Energy Particle Physics</td></tr>
<tr><td colspan="4">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="4">Module Code
SAoS HEPP</td></tr>
<tr><td colspan="2">Identification Number

MN-P-SAoS-HEPP</td><td>Workload

360 h</td><td>Credit Points

12 CP</td><td>Term

1st to 2nd semester</td><td>Offered Every

Fitting courses offered every semester, for details see course offerings</td><td>Start

Every term</td><td>Duration

2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="3">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="7">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge and specialize in the field of high energy particle physics.
The students train
• to acquire a deep understanding of the fundamentals of particle physics, in particular concerning the Standard Model of particle physics and measurements that test this model,
• to deepen understanding of experimental techniques in particle physics, from the basic physics of particle detectors to in depth treatment of particle physics at high energy colliders,
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses.</td></tr>
<tr><td>3</td><td colspan="7">Module Content
Lectures in the SAoS High Energy Particle Physics can be chosen from the list given below. For introduction, the lecture Particle Physics, physics611, is strongly recommended.
• physics611 Particle Physics, 6 CP
• physics639 Advanced Topics in High Energy Particle Physics, 6 CP
• physics633 High Energy Collider Physics, 6 CP
• physics618 Physics of Particle Detectors, 6 CP
• physics612 Accelerator Physics, 6 CP
• physics711 Particle Astrophysics and Cosmology, 6 CP
• physics719 Intensive Week: Advanced Topics in High Energy Physics, 4 CP
• and others if approved by the module coordinator</td></tr>
<tr><td>4</td><td colspan="7">Teaching Methods
Lectures, problem classes</td></tr>
</table>

5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination All courses for the module are imported from the MSc in Physics course in Bonn. For all exams, the rules of the Department of Physics/Astronomy at the University of Bonn apply. The module grade results from the weighted arithmetic mean of the individual grades.
7	Credits Awarded For the award of credit points, a sufficient number of courses from the list above has to be taken to sum-up to 12 CP. Corresponding exercises as well as exams must be passed. All courses for the module are imported from the MSc in Physics course in Bonn. For all exams. the rules of the Department of Physics/Astronomy at the University of Bonn apply.
8	Compatibility with other Curricula Not applicable – module imported from the University of Bonn.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Achim Rosch
11	Further Information Detailed information regarding possible combinations of courses and the content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 15.04.2023 AR, PN

Secondary Area of Specialization Physics in Medicine (U Bonn)

Module Name: SAoS Physics in Medicine						
Type of Module o Basic Module o Advanced Module o Specialisation Module o Supplementary Module			Module Code SAoS PhysMed			
Identification Number	Workload	Credit Points	Term	Offered Every	Start	Duration
MN-P-SAoS-PhysMed	360 h	12 CP	1st to 2nd semester	Fitting courses offered every semester, for details see course offerings	Every term	2 semesters
1	Course Types a) Lectures b) Problem classes / exercises		Contact times depending on the individual choice		Private Study depending on the individual choice	
2	Module Objectives and Skills to be Acquired In this module, students deepen previous knowledge and specialize in the field of physics in medicine. The students train • to understand the physics behind different medical diagnostic procedures, including the analysis of complex systems, • their ability to apply methods of different fields of physics like statistical, nuclear or condensed matter physics to applied problems in medicine, • to make use of an interdisciplinary approach to techniques of modern day medicine, • to solve challenging problems and to summarize and present acquired knowledge, • their self and time management skills by organizing their courses.						
3	Module Content Lectures in the SAoS Physics in Medicine can be chosen from the list given below. For introduction, the lecture Physics in Medicine I: Fundamentals of Analyzing Biomedical Signals, physics772, is strongly recommended. • physics772 Physics in Medicine I: Fundamentals of Analyzing Biomedical Signals, 6 CP • physics773 Physics in Medicine II: Fundamentals of Medical Imaging, 6 CP • physics776 Physics in Medicine: Physics of Magnetic Resonance Imaging, 6 CP • physics777 Physics in Medicine: Cardiovascular Magnetic Resonance Imaging (CMRI), 6 CP • and others if approved by the module coordinator						
4	Teaching Methods Lectures, problem classes						
5	Prerequisites (for the Module)						

	Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination All courses for the module are imported from the MSc in Physics course in Bonn. For all exams, the rules of the Department of Physics/Astronomy at the University of Bonn apply. The module grade results from the weighted arithmetic mean of the individual grades.
7	Credits Awarded For the award of credit points, a sufficient number of courses from the list above has to be taken to sum-up to 12 CP. Corresponding exercises as well as exams must be passed. All courses for the module are imported from the MSc in Physics course in Bonn. For all exams. the rules of the Department of Physics/Astronomy at the University of Bonn apply.
8	Compatibility with other Curricula Not applicable – module imported from the University of Bonn.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Achim Rosch
11	Further Information Detailed information regarding possible combinations of courses and the content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 15.04.2023 AR, PN

Secondary Area of Specialization Quantum Optics and Optical Condensed Matter Physics (U Bonn)

<table>
<tr><td colspan="7">Module Name: SAoS Quantum Optics and Optical Condensed Matter Physics</td></tr>
<tr><td colspan="4">Type of Module
o Basic Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="3">Module Code
SAoS QOCM</td></tr>
<tr><td>Identification Number</td><td>Workload</td><td>Credit Points</td><td>Term</td><td>Offered Every</td><td>Start</td><td>Duration</td></tr>
<tr><td>MN-P-SAoS-QOCM</td><td>360 h</td><td>12 CP</td><td>1st to 2nd semester</td><td>Fitting courses offered every semester, for details see course offerings</td><td>Every term</td><td>2 semesters</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Lectures
b) Problem classes / exercises</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="2">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="6">Module Objectives and Skills to be Acquired
In this module, students deepen previous knowledge and specialize in the fields of quantum optics and/or optical condensed matter physics.
The students train
• to acquire understanding of the physical and technological foundations of quantum optics and laser-based photonics,
• to gain a deeper insight into the fundamental concepts of condensed matter physics, specifically by studying the interaction of light and matter,
• to practically apply their acquired knowledge in research and development,
• to solve challenging problems and to summarize and present acquired knowledge,
• their self and time management skills by organizing their courses.</td></tr>
<tr><td>3</td><td colspan="6">Module Content
Lectures in the SAoS Quantum Optics and Optical Condensed Matter Physics can be chosen from the list given below. For introduction, the lecture Quantum Optics, physics631, is strongly recommended.
• physics631 Quantum Optics, 6 CP
• physics641 Photonics, 6 CP
• physics734 Holography, 3 CP
• physics735 Laser Cooling and Matter Waves, 3 CP
• physics736 Crystal Optics, 6 CP
• physics737 Intensive Week: Advanced Topics in Photonics and Quantum Optics, 4 CP
• physics738 Lecture on Advanced Topics in Quantum Optics, 6 CP
• physics739 Lecture on Advanced Topics in Photonics, 6 CP
• and others if approved by the module coordinator</td></tr>
</table>

4	Teaching Methods Lectures, problem classes
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination All courses for the module are imported from the MSc in Physics course in Bonn. For all exams, the rules of the Department of Physics/Astronomy at the University of Bonn apply. The module grade results from the weighted arithmetic mean of the individual grades.
7	Credits Awarded For the award of credit points, a sufficient number of courses from the list above has to be taken to sum-up to 12 CP. Corresponding exercises as well as exams must be passed. All courses for the module are imported from the MSc in Physics course in Bonn. For all exams. the rules of the Department of Physics/Astronomy at the University of Bonn apply.
8	Compatibility with other Curricula Not applicable – module imported from the University of Bonn.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Achim Rosch
11	Further Information Detailed information regarding possible combinations of courses and the content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 15.04.2023 AR, PN

Secondary Area of Specialization Theoretical Hadron Physics (U Bonn)

Module Name: SAoS Theoretical Hadron Physics						
Type of Module o Basic Module o Advanced Module o Specialisation Module o Supplementary Module			Module Code SAoS ThHad			
Identification Number	Workload	Credit Points	Term	Offered Every	Start	Duration
MN-P-SAoS-ThHad	360 h	12 CP	1st to 2nd semester	Fitting courses offered every semester, for details see course offerings	Every term	2 semesters
1	Course Types a) Lectures b) Problem classes / exercises		Contact times depending on the individual choice		Private Study depending on the individual choice	
2	Module Objectives and Skills to be Acquired In this module, students deepen previous knowledge and specialize in the field of theoretical hadron physics. The students train • to understand the theory of strong interaction, hadron structure and dynamics, • to assess and apply different methods of theoretical hadron physics in relation to current research, • their ability to compute strong interaction processes • to solve challenging problems and to summarize and present acquired knowledge, • their self and time management skills by organizing their courses.					
3	Module Content Lectures in the SAoS Theoretical Hadron Physics can be chosen from the list given below. For introduction, the lecture Theoretical Hadron Physics, physics616, is strongly recommended. • physics616 Theoretical Hadron Physics, 7 CP • physics637 Advanced Theoretical Hadron Physics, 7 CP • physics757 Effective Field Theory, 7 CP • physics758 Quantum Chromodynamics, 7 CP • and others if approved by the module coordinator					
4	Teaching Methods Lectures, problem classes					
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics.					

	Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination All courses for the module are imported from the MSc in Physics course in Bonn. For all exams. the rules of the Department of Physics/Astronomy at the University of Bonn apply. The module grade results from the weighted arithmetic mean of the individual grades.
7	Credits Awarded For the award of credit points, a sufficient number of courses from the list above has to be taken to sum-up to 12 CP. Corresponding exercises as well as exams must be passed. All courses for the module are imported from the MSc in Physics course in Bonn. For all exams, the rules of the Department of Physics/Astronomy at the University of Bonn apply.
8	Compatibility with other Curricula Not applicable – module imported from the University of Bonn.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Achim Rosch
11	Further Information Detailed information regarding possible combinations of courses and the content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 15.04.2023 AR, PN

Secondary Area of Specialization Theoretical Particle Physics (U Bonn)

Module Name: SAoS Theoretical Particle Physics						
Type of Module o Basic Module o Advanced Module o Specialisation Module o Supplementary Module			Module Code SAoS TPP			
Identification Number	Workload	Credit Points	Term	Offered Every	Start	Duration
MN-P-SAoS-TPP	360 h	12 CP	1st to 2nd semester	Fitting courses offered every semester, for details see course offerings	Every term	2 semesters
1	Course Types a) Lectures b) Problem classes / exercises		Contact times depending on the individual choice		Private Study depending on the individual choice	
2	Module Objectives and Skills to be Acquired In this module, students deepen previous knowledge and specialize in the field of theoretical particle physics. The students train • to acquire a deep understanding of the Standard Model of elementary particle physics and its extensions (unified theories), • their knowledge of the methods of theoretical high-energy physics beyond the Standard Model, in particular supersymmetry and extra dimensions with regard to current research, • to understand and apply methods of quantum field theory thereby improving their ability to compute processes in quantum electrodynamics and/or many particle systems, • to solve challenging problems and to summarize and present acquired knowledge, • their self and time management skills by organizing their courses.						
3	Module Content Lectures in the SAoS Theoretical Particle Physics can be chosen from the list given below. For introduction, the lecture Theoretical Particle Physics, physics615, is strongly recommended. • physics615 Theoretical Particle Physics, 7 CP • physics636 Advanced Theoretical Particle Physics, 7 CP • physics751 Group Theory, 7 CP • physics752 Superstring Theory, 7 CP • physics753 Theoretical Particle Astrophysics, 7 CP • physics755 Quantum Field Theory, 7 CP • physics758 Quantum Chromodynamics, 7 CP • physics761 Supersymmetry, 7 CP • and others if approved by the module coordinator						

4	Teaching Methods Lectures, problem classes
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Experimental and theoretical physics at the level of the bachelor courses in physics. Individual courses may have additional prerequisites, see lecture descriptions online.
6	Type of Examination All courses for the module are imported from the MSc in Physics course in Bonn. For all exams, the rules of the Department of Physics/Astronomy at the University of Bonn apply. The module grade results from the weighted arithmetic mean of the individual grades.
7	Credits Awarded For the award of credit points, a sufficient number of courses from the list above has to be taken to sum-up to 12 CP. Corresponding exercises as well as exams must be passed. All courses for the module are imported from the MSc in Physics course in Bonn. For all exams. the rules of the Department of Physics/Astronomy at the University of Bonn apply.
8	Compatibility with other Curricula Not applicable – module imported from the University of Bonn.
9	Proportion of Final Grade The weight of the module is 12/111.
10	Module Coordinator Achim Rosch
11	Further Information Detailed information regarding possible combinations of courses and the content of individual courses can be found on the website of the M. Sc. in Physics course. Version: 15.04.2023 AR, PN

Introductory Project I

Module Name: Introductory Project I						
Type of Module o Core Module o Advanced Module o Specialisation Module o Supplementary Module			Module Code Introductory 1			
Identification Number	Workload	Credit Points	Term	Offered Every	Start	Duration
MN-P-Intro1	360 h	12 CP	3rd semester	Continuously (not bound to lecture times)	Every term	3 months
1	Course Types a) Project work		Contact times approx. 180 h		Private Study approx. 180 h	
2	Module Objectives and Skills to be Acquired Orientation and practice in an extensive research subject of modern physics and presentation of scientific results.					
3	Module Content Both introductory projects I and II provide a basis for the Master thesis and should have a topical cohesion with the latter. As a general rule, the topic of the introductory projects and the Master thesis cover an extensive research subject in the area of specialization selected by the student.					
4	Teaching Methods Project work, guidance to independent research					
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Successful completion of the modules or courses provided for in the curriculum in the first two semesters. Sufficient knowledge in the respective area of specialization. This module needs to be registered in the examination office prior to its beginning.					
6	Type of Examination The modules Introductory Project I and Introductory Project II are completed with an approx. 20-minute presentation on the topic of the corresponding Introductory Project. By mutual agreement, the presentation for the Introductory Project I may be replaced by a poster presentation or a report according to § 12 subparagraph 3 (d). The presentation is graded as passed or failed. A failed presentation can be repeated. The module is passed if the presentation is passed.					
7	Credits Awarded The successful passing of the presentation.					
8	Compatibility with other Curricula None.					

9	Proportion of Final Grade The Introductory Project I is not graded.
10	Module Coordinator The chairperson of the examination board.
11	Further Information To register for the Introductory Project I students also have to hand-in the protocol of the first advisory meeting according to § 10 subparagraph 8 examination regulations. Version: 17.04.2023 LL, PN

Introductory Project II

Module Name: Introductory Project II						
Type of Module o Core Module o Advanced Module o Specialisation Module o Supplementary Module			Module Code Introductory 2			
Identification Number	Workload	Credit Points	Term	Offered Every	Start	Duration
MN-P-Intro2	360 h	12 CP	3rd semester	Continuously (not bound to lecture times)	Every term	3 months
1	Course Types a) Project work		Contact times approx. 180 h		Private Study approx. 180 h	
2	Module Objectives and Skills to be Acquired Consolidation in an extensive area of research of modern physics and presentation of the corresponding scientific results.					
3	Module Content Both Introductory Projects I and II provide a basis for the Master thesis and should have a topical cohesion with the latter. As a general rule, the topic of the Introductory Projects and the Master thesis cover an extensive research subject in the area of specialization selected by the student. The Introductory Project II builds on the insights gained in the Introductory Project I and serves as an additional consolidation in preparation of the Master thesis.					
4	Teaching Methods Project work, guidance to independent research					
5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: Successful completion of the modules or courses provided for in the curriculum in the first two semesters as well as the Introductory Project I. Sufficient knowledge in the respective area of specialization.					

6	Type of Examination The modules Introductory Project I and Introductory Project II are completed with an approx. 20-minute presentation on the topic of the corresponding Introductory Project. The presentation is graded as passed or failed. A failed presentation can be repeated. The module is passed if the presentation is passed.
7	Credits Awarded The successful passing of the presentation.
8	Compatibility with other Curricula None.
9	Proportion of Final Grade The Introductory Project II is not graded.
10	Module Coordinator The chairperson of the examination board.
11	Further Information Version: 05.04.2023 PN

2.4 Supplementary Modules

Besides the two Areas of Specialization, students gain knowledge on additional topics of natural sciences and mathematics in the Elective Area. Courses from different areas may be combined for a total of at least 12 LP. Each individual course must have at least 3 CP. Several courses from the same field form a subject (e.g. two mathematics courses will form the subject Mathematics).

Elective Area

<table>
<tr><td colspan="8">Module Name: Elective Area</td></tr>
<tr><td colspan="4">Type of Module
o Core Module
o Advanced Module
o Specialisation Module
o Supplementary Module</td><td colspan="4">Module Code
Elective</td></tr>
<tr><td colspan="2">Identification Number

MN-P-WaMa</td><td>Workload

360 h</td><td>Credit Points

12 CP</td><td>Term

1st to 2nd semester</td><td>Offered Every

Every term</td><td>Start

Every term</td><td>Duration

2 semesters</td></tr>
<tr><td>1</td><td colspan="3">Course Types
a) Lectures
b) Problem classes / exercises
c) Seminar
d) Lab course</td><td colspan="2">Contact times
depending on the individual choice</td><td colspan="2">Private Study
depending on the individual choice</td></tr>
<tr><td>2</td><td colspan="7">Module Objectives and Skills to be Acquired
The elective area offers room for individual profiling and subject-related supplementation according to the students' interests.</td></tr>
<tr><td>3</td><td colspan="7">Module Content
The Elective Area module is usually composed of two advanced courses (or modules) from other areas of the faculty for mathematics and natural sciences and/or a physical specialization not yet selected in the PAoS or SAoS, including modules in physics offered by the University of Bonn.
The courses and/or modules that can be selected in the Elective Area are announced by the examination board by notice or on the internet in a suitable form. Courses or modules from different areas with a total of at least 12 CP may be combined.
If not credited elsewhere, either of both courses “Advanced Quantum Mechanics” and “Advanced Statistical Physics” may be credited here.</td></tr>
<tr><td>4</td><td colspan="7">Teaching Methods
The organization of the selectable modules/courses is carried out by the respective departments. These can be, for example, lectures with exercises or courses with a different structure.</td></tr>
</table>

5	Prerequisites (for the Module) Formal: Enrolment in the M. Sc. in Physics course in Cologne In terms of content: See descriptions of the respective modules/courses.
6	Type of Examination Depends on the choice of the students. See corresponding module descriptions of the respective departments. If the elective area is fulfilled with only one course or module, the examination grade is the module grade. If the elective consists of several courses or subjects, the grade for the module is the weighted arithmetic average of the grades for the individual courses/subjects. (A subject is a set of courses which will be graded in one examination.) If students achieve more than 12 CP in the Elective Area, they may choose which 12 out of these CP are to be used for the weighted average. According to § 6 subparagraph 7 examination regulations, the module examination can consist of a maximum of three examination elements. Unless otherwise regulated, the rules of the organizing department or faculty apply to imported modules (§ 5 subparagraph 4).
7	Credits Awarded See descriptions of the respective modules/courses.
8	Compatibility with other Curricula As elective subject in other M. Sc. programs.
9	Proportion of Final Grade The grade for the module is the weighted arithmetic average of the grades for the individual subjects. A subject is a set of courses which will be graded in one examination. If students achieve more than 12 CP in the Elective Area, they may choose which 12 out of these CP are to be used for the weighted average. The weight of the module is 12/111.
10	Module Coordinator The chairperson of the examination board.
11	Further Information Version: 17.04.2023 LL, PN

2.5 Master Thesis

The master studies are completed by the Master Thesis. The students work independently on a well-defined problem of current physics research. The topic of the Master Thesis is usually closely connected to the topics of the two introductory projects. The scientific results of this work are documented in a written thesis and presented orally in a colloquium.

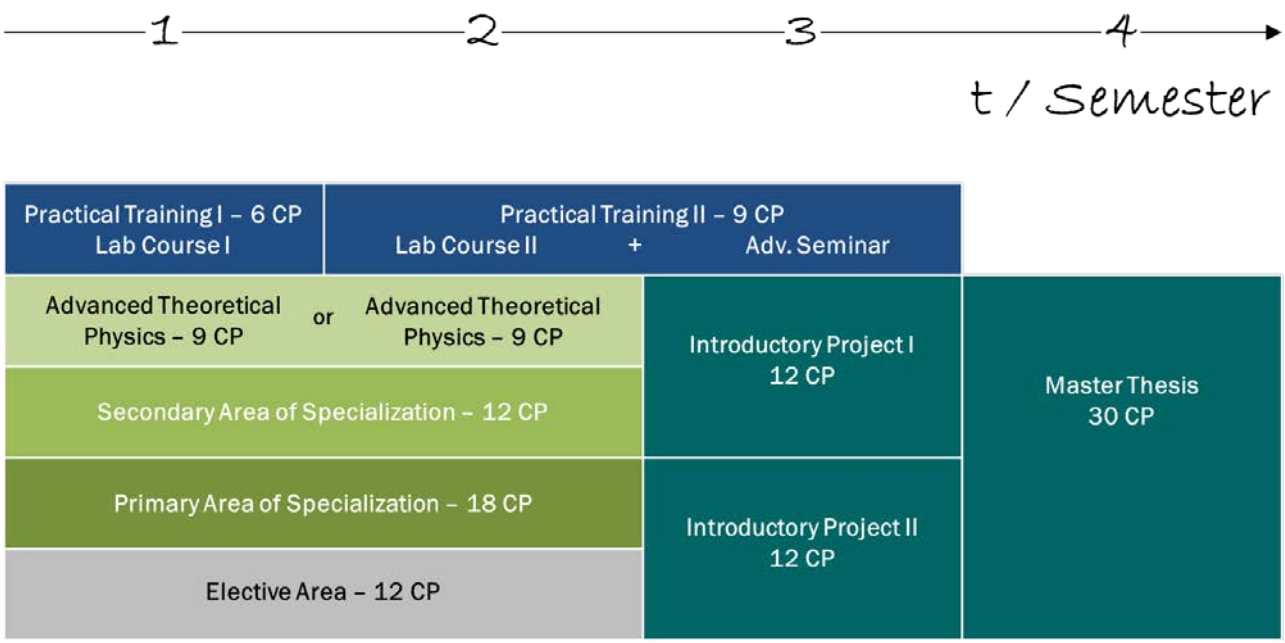
<table>
<tr><td colspan="8">Module Name: Master Thesis</td></tr>
<tr><td colspan="5">Type of Module
o Master Thesis</td><td colspan="3">Module Code
Thesis</td></tr>
<tr><td>Identification Number</td><td>Workload</td><td>Credit Points</td><td>Term</td><td>Offered Every</td><td>Start</td><td colspan="2">Duration</td></tr>
<tr><td>MN-P-MT</td><td>900 h</td><td>30 CP</td><td>4th semester</td><td>Continuously (not bound to lecture times)</td><td>Every term</td><td colspan="2">6 months</td></tr>
<tr><td>1</td><td colspan="2">Course Types
a) Project
b) Colloquium</td><td colspan="2">Contact times
According to the individual demand of the student</td><td colspan="3">Private Study
According to the individual demand of the student</td></tr>
<tr><td>2</td><td colspan="7">Module Objectives and Skills to be Acquired
Students acquire the scientific skills that are needed to carry out a substantial research project on one of the current topics of physics. They develop considerably in presenting their results in written and oral form. Additionally, they train to defend their scientific achievements and to develop their own ideas within their field of interest. They also learn to finalize a project in time and to manage their time efficiently.</td></tr>
<tr><td>3</td><td colspan="7">Module Content
As an integral part of the M. Sc. program, each student works on his/her own research project. The results of the project are written up as M. Sc. thesis. The thesis work is preceded by the Introductory Projects I and II which introduce the student to the topic of the M.Sc. thesis and are evaluated separately. As a rule, the introductory projects and the M.Sc. thesis research are substantial pieces of scientific work, carried out in the area of specialization chosen by the student.
The topic to be worked on is issued by the chairman of the examination board in consultation with the student's thesis research advisor.</td></tr>
<tr><td>4</td><td colspan="7">Teaching Methods
Project work, guidance to independent research</td></tr>
<tr><td>5</td><td colspan="7">Prerequisites (for the Module)
Formal: Enrolment in the M. Sc. in Physics course in Cologne
In terms of content: Passed examinations of all other modules of the Master course and the contents of the previously completed Introductory projects I and II.</td></tr>
<tr><td>6</td><td colspan="7">Type of Examination
The Master Thesis and the colloquium will be evaluated by two and in the exceptional case by three referees.
On the day of the colloquium the referee report/reports to the master thesis have to be present. The grading of the colloquium takes place on the day of the colloquium.</td></tr>
</table>

7	Credits Awarded The module is passed by successfully preparing the M. Sc. thesis and by passing the colloquium.
8	Compatibility with other Curricula None.
9	Proportion of Final Grade The total grade given for the module is the 3:1 weighted average of the two grades given for the written thesis and the colloquium talk. The weight of the module is 45/111
10	Module Coordinator The chairperson of the examination board.
11	Further Information Version: 05.04.2023 PN

3 Study Aids

3.1 Sample Study Plan

The Department of Physics recommends performing the studies according to the following plan. In general the study plan strongly depends on the individual choices and the selected areas of specialization. The different courses of each subject can be arranged individually. Also, a number of courses is not offered every year. Therefore it is recommended to plan the courses early on. In case of major deviations from the study plan provided below, students are strongly advised to check their plan with the Student Advisory Service.



3.2 Subject and Exam Counseling

In addition to the services of the Central Student Guidance and Counseling Services of the University of Cologne, the Department of Physics offers a special counseling for physics students (Dr. Frank Lewen and Dr. Petra Neubauer-Guenther). This counseling addresses bachelor students who consider continuing their studies up to the M. Sc. and master students at all stages before and during their studies.

An open consultation-hour is offered on a weekly basis during the whole year. Besides, also individual appointments can be arranged on short notice. Detailed information can also be provided via email or phone.

The counseling also addresses questions concerning examinations and their organization. Detailed questions on individual modules will be answered by the module coordinators. Detailed questions concerning examinations will also be answered by the examination office.

3.3 Further Offers of Information and Counseling

Members of the BCGS scholarship program are entitled to choose two mentors, one in Cologne and one in Bonn. These mentors will provide support for the organization and planning of the studies, as well as on subject questions.

The students' council organized by the physics students in Cologne also provides substantial support on any questions related to the studies.

Students who aim to perform part of their studies abroad via the **Erasmus Program** may contact Prof. Erwann Bocquillon further counseling.

Further counseling offers at the University of Cologne are:

Central Student Guidance and Counseling Services (Zentrale Studienberatung) *https://verwaltung.uni-koeln.de/abteilung21/content/index_eng.html*	General questions concerning studies, choice of subjects, etc.
International Office *https://portal.uni-koeln.de/en/international/study-in-cologne*	Questions concerning enrolment for international students, Visa issues, etc.
Student Application and Registration Office (Studierendensekretariat) *https://verwaltung.uni-koeln.de/studsek/content/index_eng.html*	Questions concerning enrolment for German students, etc.
Kölner Studierendenwerk *http://www.kstw.de/*	Social aspect concerning the studies esp. housing, etc.
ASTA *http://www.asta.uni-koeln.de/*	Student representation
Representatives for students with disabilities or chronic illnesses https://inklusion.uni-koeln.de/beauftragte_fuer_studierende_mit_behinderung_oder_chronischer_erkrankung/index_ger.html	Studying with a disability or chronic illness
Central Gender Equality Officer *http://www.gb.uni-koeln.de/*	Compatibility of family and studies, sexualized discrimination