Notice:

This English translation of the Examination Regulations for the Master's Degree Program in Physics is solely provided for the convenience of international students. While care has been taken to ensure that the translation is accurate, only the German version of these Examination Regulations, which has been published in the Official Bulletin of Paderborn University, is legally binding.

Special provisions of the examination regulations for the Master's program in Physics at the Faculty of Natural Sciences at the University of Paderborn

of April 11, 2024

On the basis of Section 2 (4) and Section 64 (1) of the Law on Higher Education Institutions in North Rhine-Westphalia (Higher Education Act – HG) of September 16, 2014 (GV.NRW. p. 547), last amended by Article 2 of the Law of December 5, 2023 (GV. NRW. p. 1278), Paderborn University has issued the following regulations:

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§ 31
General and Special Provisions

These Special Provisions apply in conjunction with the General Provisions for the examination regulations of the Master's programs of the Faculty of Natural Sciences at the University of Paderborn in their currently valid version (General Provisions). A study plan is included in the appendix to ensure the proper structure of the program. Details on the modules can be found in the module descriptions in the appendix, which form part of these Special Provisions.

§ 32
Acquisition of skills and language regulations

(1) The master's examination constitutes a second professionally qualifying degree in physics. In addition to the general study objectives set out in Section 58 (1) of the Higher Education Act, the program provides students with in-depth knowledge of mathematics and natural sciences, an overview of internal physical relationships, and knowledge in a specialized field that is compatible with current international research, enabling them to analyze, formulate, and, to a large extent, solve complex physical problems and tasks on a scientific basis. Students also acquire the ability to familiarize themselves with any specialized field of physics, to research the current international literature on the subject, to independently plan, carry out, and interpret experiments for problem solving, and to independently model and simulate on the basis of theoretical principles. In addition to these subject-specific skills, students also acquire social skills, an awareness of their responsibility towards science and the principles of good scientific practice, and the ability to discuss complex issues and their own research results in the context of current research and to present them in writing and orally.

(2) The master's program and master's examination are conducted in German or English. The respective language is indicated in the module descriptions.

§ 33
Academic degree

Upon successful completion of the master's program, the academic degree "Master of Science" (M.Sc.) is awarded.

§ 34
Start of studies

The program can be started in the winter semester or the summer semester.

§ 35
Admission requirements

(1) In accordance with § 5 of the General Provisions, the program requires a degree that includes the competencies described below, as taught, for example, in the Bachelor's program in Physics at the University of Paderborn:

a. Experimental physics: Mastery of the fundamental concepts of classical physics (mechanics, electrodynamics, optics, thermodynamics) as well as quantum, atomic, and solid-state physics.
b. Theoretical physics: Mastery of the theoretical fundamentals and methods of classical mechanics, electrodynamics, quantum mechanics, and thermodynamics, combined with the ability to model and formulate physical phenomena in abstract mathematical terms.
c. Physics practicals: Recognizing and extracting essential physical relationships based on experiments conducted by the student, recording and critically evaluating the experimental results.
d. Mathematics: Mastery of the fundamental mathematical concepts and methods required to understand and solve problems in the Master's program in Physics. This involves in-depth knowledge in the areas of linear algebra, analysis, differential equations, and vector analysis.

The examination board will determine whether the prerequisites have been met.

(2) The degree must have been completed with an overall grade of at least 3.0 (or an equivalent foreign final grade), or the "Bachelor's Thesis" module must have been completed with a grade of at least 2.0.

(3) If requirements are missing, enrollment may be granted on condition that the requirements are made up for by appropriate studies and that the student passes the relevant examinations before registering for the modules of the research phase. The decision on this, as well as on the type and scope of the studies and examinations, is made by the examination board on the basis of the previous degree. Examinations successfully completed outside of the degree program may also be taken into account. The missing studies that need to be made up may not exceed 30 credit points. The studies and examinations should be completed in the first semester of the master's program.

(4) In addition to the requirements specified in § 5 of the General Provisions, the following further admission requirement applies:

Foreign language skills in English at level B2 of the Common European Framework of Reference for Languages (CEFR) are required. English language skills must be demonstrated as follows:

a. Bachelor's degree from an English-speaking country or from a domestic degree program accredited as English-speaking, or
b. Test of English as a Foreign Language (TOEFL) "internet-based" test (iBT, including Home Edition and Paper Edition) with a score of at least 80 points, or
c. IELTS test with a score of at least 6.0, or
d. Cambridge Test – First Certificate in English (FCE) or
e. through tests of equivalent level or
f. corresponding school education.

(5) Contrary to § 5 (1) No. 3 of the General Provisions, German language skills are not required.

(6) If the applicant has definitively failed an examination required by the examination regulations in their previous degree program at a university within the scope of the Basic Law, and if the previous degree program is very similar in content to the Master's degree program in Physics, enrollment will be refused under the conditions of § 5 (3) of the General Provisions.

§ 36
Structure, course content, modules

(1) The following specializations can be chosen in the Master's program in Physics:
- General Physics,
- Photonic Quantum Technologies,
- Optoelectronics, Materials, Devices

(2) If no choice is made, the student will be assigned to the "General Physics" specialization. A change of specialization is possible at any time upon application to the Central Examination Office.

(3) The following modules must be completed as part of the master's program:
- Two elective modules from the "Experimental Physics" module group, each worth 6 CP
- Quantum Mechanics module: compulsory module with 8 CP
- Three elective modules from the "Specialization" module group, each worth 6 CP.
- Advanced Seminar module: Compulsory module with 4 CP.
- Technical English II module: compulsory module with 6 CP.
- Two elective modules from the "Theoretical Physics" module group, each worth 6 CP
- Preparation for the master's thesis: Theory with 15 CP
- Preparation for the master's thesis: Methodology with 15 CP.
- Master's thesis module: Compulsory module with 30 CP.

(4) If the major "General Physics" is chosen, the elective modules mentioned in paragraph (3) can be chosen freely within the respective module group.

(5) If the "Photonic Quantum Technologies" study option is chosen, the choices listed in paragraph (3) are restricted as follows:
- One of the two compulsory elective modules from the "Experimental Physics" module group must be the "Quantum Optics" module.
- In addition, in the module group "Specialization," either the module "Quantum Electronics" or "Integrated Optics and Photonics" or "Quantum Communication and Quantum Information Processing" must be completed.
- One of the three compulsory elective modules from the module group "Specialization" must be the module "Introduction to Quantum Computing." In the module group "Theoretical Physics," the module "Quantum Information Theory" must be completed.

(6) If the "Optoelectronics, Materials, Devices" study option is chosen, the options listed in paragraph (3) are restricted as follows:
- In the module group "Experimental Physics," either the module "Physics and Technology of Nanomaterials" or the module "Semiconductor Heterostructures: Fundamentals and Applications" must be completed.
- In the module group "Experimental Physics," either the module "Nonlinear Optics" or the module "Project Internship" must be selected.
- From the module group "Specialization," the module "Optoelectronic Semiconductor Devices" must be selected.
- From the module group "Specialization," either the module "Computational Optoelectronics and Photonics 1" or the module "Integrated Optics and Photonics" must be selected.

§ 37
Participation requirements, admission

(1) The module descriptions set out the requirements for participation in a module in accordance with Section 7 (2) of the General Provisions.

(2) Only those who have achieved at least 48 LP and, in the case of enrollment under conditions pursuant to § 4, have demonstrated that they have passed the relevant examinations may be admitted to the research phase.

(3) Only those who have successfully completed the modules "Preparation for the Master's Thesis: Theory" and "Preparation for the Master's Thesis: Methodology" of the research phase at the time of application for admission may be admitted to the Master's thesis.

(4) Further requirements for participation in examinations in accordance with § 12 (2) of the General Provisions are regulated in the module descriptions.

§ 38 Examiners

The group of examiners may be expanded within the framework of § 65 HG.

§ 39
Performance in the modules

(1) Performance in the modules must be in accordance with the module descriptions.

(2) Examination performance shall be provided in accordance with § 15 of the General Provisions in the form of written examinations, oral examinations, written assignments, or in other forms. The following other forms are specifically provided for:

1. Presentation:

   Presentations are oral presentations on a topic that students have researched independently within the thematic scope of a course. The aim is for students to demonstrate that they are capable of researching and academically elaborating on a given topic and communicating their findings. The topic is agreed upon with the instructor.

2. Set of experiments

   The exam consists of a specified number of experiments from a catalog of experiments structured by content. An experiment comprises preparation (including literature research), implementation (including reflections on comments from supervisors), written elaboration (practical report including literature research), presentation, and a discussion of the written elaboration. A grade is awarded for the entirety of the written elaborations (including presentations and discussions) of the experiments.

   In the practical training sessions, candidates must demonstrate that they are able to prepare an experimental task appropriately, carry it out taking safety aspects into account, evaluate it, and document it. In order to practice cooperation and for safety reasons, the experiments are usually carried out in small groups of two to four students. Participation in the practical training days is mandatory.

Before the start of each experiment, the supervisor must ensure that the students are sufficiently prepared to carry out the experiment successfully and safely. If this is not the case, the experiment may only be carried out at a later date.

3. Portfolio
   The final portfolio comprises comprehensive written reports on individually specified topics based on the experiments carried out, as well as a final discussion. An experiment comprises preparation (including literature research), implementation (including reflections on comments from supervisors), written work (internship report of approx. 10 pages without appendices, including literature research), presentation, and a discussion of the written work lasting approx. 15 minutes. A grade is given for the entirety of the written papers (including presentations and discussions) for the four attempts. The written papers (including presentations and discussions) for the attempts are weighted equally in the assessment of the exam.
4. Written assignment
   A written assignment is a form of examination in which the candidate demonstrates their knowledge and skills by writing a text on a specific topic. It allows the candidate's understanding and abilities to be assessed in terms of the application and integration of knowledge, the analysis of complex concepts, and the ability to communicate in writing.
   A written assignment is usually completed individually. The examinee is given a specific question or topic on which they must write a text. This text should usually be around 500 words long, but may vary depending on the complexity and requirements of the topic.
   The written task allows the examinee to demonstrate their knowledge and skills in a way that requires a more in-depth and detailed analysis than in an oral exam format. In addition, it allows the examinee to demonstrate their written communication and argumentation skills.
   The written assignment is assessed on the basis of the quality and depth of the analysis, the relevance and accuracy of the knowledge used, the structure and coherence of the text, and the effectiveness of the written communication.
5. Written assignment followed by presentation
   A "written assignment followed by a presentation" is a form of examination in which the examinee demonstrates their knowledge and skills in a combination of written and oral presentation.
   The written assignment allows the examinee to explore and analyze a specific topic in depth. This assignment should generally be around 10 pages long, but may vary depending on the complexity of the topic and the examiner's requirements. The term paper requires the examinee to conduct thorough literature research, formulate their thoughts clearly and in a structured manner, and substantiate their arguments and conclusions with evidence and supporting documentation.
   After completing the written paper, the examinee presents their findings and conclusions in an oral presentation, which usually lasts 25 minutes. This presentation gives the examinee the opportunity to demonstrate their oral communication and presentation skills and to discuss and defend their approach, findings, and conclusions.
   Compared to the "written assignment with final presentation" exam format, the "written assignment with subsequent presentation" format places greater emphasis on the integration of written and oral communication skills. While both

forms of examination, a written paper is produced and presented, the "written paper with subsequent presentation" is primarily about presenting and discussing the results of the paper in an oral format, rather than a formal final presentation based on the paper.

6. Written paper with final presentation
   The "written paper with final presentation" examination format consists of two interrelated components: a comprehensive written paper and a final presentation based on it.
   The written paper requires students to research and analyze a specific topic in a particular subject area and report on it in a detailed, formally structured paper. The paper should generally be around 30 pages long, depending on the specific requirements and complexity of the topic. It offers students the opportunity to conduct in-depth research and demonstrate their ability to analyze and present complex scientific concepts in writing.
   After completing the written term paper, students prepare a final presentation that presents the most important findings and conclusions from the written paper. The final presentation usually lasts 30 minutes and gives students the opportunity to demonstrate their oral presentation skills and deepen their understanding of their topic. In addition, the final presentation serves to respond to feedback and questions from examiners and possibly other students.
   The "written paper with final presentation" exam format differs from the "written paper with subsequent presentation" format mainly in terms of the scope of the paper and the type of presentation. While the "written paper with subsequent presentation" requires a shorter paper (approx. 10 pages) and the presentation often takes place immediately after the paper is completed, the "written paper with final presentation" requires a more extensive paper (approx. 30 pages) and a more formal, structured final presentation. The final presentation is often public and requires more intensive preparation and a deeper understanding of the topic.

(3) The duration of a written exam is 60 to 180 minutes.

- The duration of an oral examination is 30 to 45 minutes.
- The duration of a presentation is approximately 30 minutes.
- The length of a written assignment is 30,000-40,000 characters.
- A written assignment has a length of approximately 500 words.
- A written assignment followed by a presentation is approximately 10 pages long (assignment) and lasts approximately 25 minutes (presentation).
- A written assignment with a final presentation is approximately 30 pages long (assignment) and lasts approximately 30 minutes (final presentation).

Further details are specified in the module descriptions.

(4) The following are particularly relevant for qualified participation:

- Exercises, which are usually set weekly as homework and/or classroom assignments.
- Project work,
- written presentation preparation,
- Certificate.

Further details are specified in the module descriptions. If the module descriptions contain framework specifications, the respective instructor determines what constitutes qualified participation.

This will be announced by the respective lecturer and in the Campus Management System of the University of Paderborn or in another suitable manner no later than in the first three weeks of the lecture period.

(5) If the module descriptions contain framework specifications regarding the form, duration, or scope of examination requirements, the examination board shall determine, in consultation with the examiner, how the examination requirement is to be fulfilled in concrete terms. This shall be announced by the respective lecturer and in the Campus Management System of the University of Paderborn or in another suitable manner no later than in the first three weeks of the lecture period.

§ 40
Master's thesis

(1) The master's thesis should be between 40 and 80 pages long (150,000 to 200,000 characters, excluding appendices). The processing time for the master's thesis is 20 weeks. The master's thesis should be started no later than six weeks after completion of the preparatory modules of the research phase.

(2) An oral defense in accordance with § 19 of the General Regulations is required. The oral defense consists of a presentation on the main findings and thematic focus of the thesis, lasting approximately 25 minutes. Following the presentation, the examiners will have the opportunity to ask questions. The total duration of the oral defense should not exceed 60 minutes. The master's thesis and oral defense are weighted 5:1 in the calculation of the final grade for the final module.

§ 41
Overall grade

The overall grade is calculated in accordance with § 21 of the General Regulations.

§ 42
Additional work

Students may perform additional services in accordance with § 20 of the General Provisions in modules of the degree program that are not limited in terms of participant numbers.

Section 43
Repeating examinations

The number of examination attempts pursuant to § 22 (1) of the General Provisions is limited to four.

Section 44
Transitional provisions

(1) These Special Provisions apply to all students who are enrolled for the first time in the Master's program in Physics at the Faculty of Natural Sciences at Paderborn University starting in the winter semester 2024/2025.

(2) Students who enrolled in the Master's program in Physics at Paderborn University before the 2024/2025 winter semester will take their Master's examination, including repeat examinations, for the last time in the 2026/2027 winter semester2027 in accordance with the examination regulations for the Master's program in Physics at the Faculty of Natural Sciences at the University of Paderborn dated June 16, 2017 (AM.Uni.Pb. 48.17). After that, the Master's examination, including repeat examinations, will be taken in accordance with these Special Provisions. Upon application to the examination board, it is possible to switch to these special provisions earlier. The application is irrevocable.

§ 45
Entry into force, expiry, and publication

(1) The Special Provisions shall enter into force on October 1, 2024. At the same time, the examination regulations for the Master's program in Physics at the Faculty of Natural Sciences at the University of Paderborn dated June 16, 2017 (AM.Uni.Pb. 48.17) shall cease to be valid. § 44 remains unaffected.

(2) The Special Provisions will be published in the Official Announcements of the University of Paderborn (AM.Uni.Pb.).

(3) In accordance with § 12 (5) HG, one year after the publication of these regulations, violations of procedural or formal requirements of the Higher Education Act or of the regulations or other autonomous law of the university can no longer be asserted against these regulations, unless

1. the regulations have not been properly announced,
2. the Presidium has previously objected to the decision of the body adopting the regulations,
3. the procedural or formal defect has been previously reported to the university, specifying the legal provision that has been violated and the fact that constitutes the defect, or
4. the legal consequence of the exclusion of complaints was not pointed out in the public announcement of the regulations.

Issued on the basis of the decision of the Faculty Council of the Faculty of Natural Sciences on May 3, 2023, and after review of its legality by the Presidium of Paderborn University on June 28, 2023.

Appendix 1:
Study plan: Study option "General Physics"

Semester	Module	LP	Workload (h)
1	One elective module from the experimental physics module group	6	18
	One elective module from the Specialization module group	6	180
	One elective module from the specialization module group	6	180
	Quantum Mechanics II	8	180
	Advanced Seminar		60
	Technical English II		90
Total		**31**	**930**
2	An elective module from the theoretical physics module group	6	180
	One elective module from the Specialization module group	6	180
	One elective module from the Experimental Physics module group	6	180
	One elective module from the theoretical physics module group	6	180
	Advanced seminar		60
	Technical English II		90
Total		**29**	**870**
3	Preparation module: Theory	15	450
	Preparation module: Methodology	15	450
Total		**30**	**900**
4	Master's thesis	30	900
Total		**30**	**90**

The study plan shown is a recommendation and guide and can be customized to suit individual needs. Please note the prerequisites for enrolling in certain modules as specified in the module descriptions. Modules that are specific to this study option are highlighted in italics.

Study plan: Photonic Quantum Technologies study variant

Semester	Module	LP	Workload (h)
1	*Quantum optics*	6	180
	Introduction to quantum computing	6	180
	An elective module from the specialization module group	6	180
	Quantum Mechanics II	8	240
	Advanced Seminar		60
	Technical English II		90
Total		**31**	**930**
2	*Quantum information theory*	6	180
	Elective module *- Quantum Electronics or* *- Integrated Optics and Photonics or* *- Quantum Communication and Quantum Information Processing*	6	180
	One elective module from the experimental physics module group	6	180
	One elective module from the theoretical physics module group	6	180
	Advanced seminar	2	60
	Technical English II	3	90
Total		**29**	**870**
3	Preparation module: Theory	15	450
	Preparation module: Methodology	15	450
Total		**30**	**900**
4	Master's thesis	30	900
Total		**30**	**900**

The study plan shown is a recommendation and guide and can be customized to suit individual needs. Please note the prerequisites for enrolling in certain modules as specified in the module descriptions. Modules that are specific to this study option are highlighted in italics.

Study plan: "Optoelectronics, Materials, Devices" study option

Semester	Module	LP	Workload (h)
1	*Elective module* *- Physics and Technology of Nanomaterials or* *- Semiconductor heterostructures: Fundamentals and applications.*	6	180
	Optoelectronic semiconductor devices	6	180
	Elective module *- Computational Optoelectronics & Photonics 1or* *- Integrated Optics and Photonics*	6	180
	Quantum Mechanics II	8	240
	Advanced Seminar LV a), b) or c)		60
	Technical English II LV a)		90
Total		**31**	**930**
2	One elective module from the theoretical physics module group	6	180
	An elective module from the specialization module group	6	180
	Elective module *- Nonlinear Optics or* *- Project internship*	6	180
	One elective module from the module group Theoretical Physics	6	180
	Advanced seminar LV a), b) or c)		60
	Technical English II LV b)		90
Total		**29**	**870**
3	Preparation module: Theory	15	450
	Preparation module: Methodology	15	450
Total		**30**	
4	Master's thesis	30	
Total		**30**	

The study plan shown is a recommendation and guide and can be customized to suit individual needs. Please note the prerequisites for enrolling in certain modules as specified in the module descriptions. Modules that are specific to this study option are highlighted in italics.

Appendix 2:
Module Descriptions

Module group Experimental Physics

Nonlinear Optics							
Nonlinear Optics							
Module No. 1a	**Workload (h):** 180	**LP:** 6	**Semester:** 2	**Rotation:** SS	**Duration (in semesters):** 1	**Language:** de/en	**P/WP:** WP

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Nonlinear optics	V	30	60	WP	30
b)	Nonlinear optics	Ü	30	60	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Nonlinear optical susceptibility (description of nonlinear optical processes, formal definition and properties of nonlinear susceptibility)
- Wave optical description of nonlinear interactions (wave equation for nonlinear optical media, phase matching, Manley-Rowe relation, SHG and SFG, nonlinear optics at interfaces)
- Intensity-dependent refractive index (semiconductor nonlinearities, pulse propagation and solitons, optical phase conjugation, optical bistability)
- Electro-optic and photorefractive effects (electro-optic effect, electro-optic modulators, photorefractive effect)

5 Learning outcomes / competencies:

Students should be able to apply the fundamental concepts of nonlinear optics correctly and soundly to problems in physics and work on them independently.

Students

- can identify and analyze problems in the field of nonlinear optics and distinguish them from linear optics,
- can apply approximations to solve nonlinear wave equations,
- can independently identify problems in nonlinear optics and develop appropriate solution strategies for standard problems involving nonlinear effects,
- are able to apply simple abstractions of more complex problems when dealing with nonlinear optics and transfer these to approximations for solving the problem,
- have the ability to independently assess more complex physical relationships in the field of nonlinear optics and, using the knowledge they have acquired, evaluate numerical or analytical

	approaches to solutions in relation to their approximations, ▪ can independently engage with current English-language specialist literature on the subject of nonlinear optics.
6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Optoelectronics and Photonics.
12	**Module coordinator:** Prof. Dr. Thomas Zentgraf, Prof. Dr. Christine Silberhorn
13	**Other information:** None

Physics and Technology of Nanomaterials

Physics and Technology of Nanomaterials

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
1b	180	6	1	Every winter semester	1	German/English	WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Physics and technology of nanomaterials	V	45	90	WP	30
b)	Physics and Technology of Nanomaterials	Ü	15	30	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Thermodynamic and crystallographic fundamentals and properties of nanomaterials
- Production of thin films from the liquid phase and vacuum, epitaxy, wetting and de-wetting
- Structuring and modification of thin films using thermal, wet chemical, ion beam-assisted, and plasma-based processes
- Lateral structuring of thin films and surfaces using conventional and modern lithography processes
- Production, processing, and application of one-, two-, and three-dimensional nano-objects (nanowires and -tubes, graphene and other 2D materials, nanoclusters, quantum dots, core-shell structures)

5 Learning outcomes / competencies:

Students should be able to develop technological concepts for the production of nanostructured materials and surfaces and assess their prospects of success.

Students

- understand the special properties that materials acquire through nanostructuring,
- are familiar with different basic concepts and processes for producing structures that have nanoscale dimensions in one, two, or three dimensions,
- understand the physical background of these processes on an atomic or molecular basis,
- can apply the qualitative and quantitative models that describe such processes,
- have the ability to apply the methods they have learned to new questions and material systems in an interdisciplinary manner and to combine them in different ways,
- are able to independently acquire additional nanostructure manufacturing technologies by studying specialist literature and Internet sources and to present them in a reflective manner.

6	**Examination:** [X] Module final examination (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Optoelectronics and Photonics and in the Master's program in Materials Science.
12	**Module coordinator:** Prof. Dr. Jörg Lindner, NN
13	**Other information:** None

Quantum optics

Quantum Optics

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
1c	180	6	1	WS	1	German/English	WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Quantum optics	V	30	60	WP	30
b)	Quantum optics	Ü	30	60	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

This module covers the fundamental concepts required to understand quantum optics with light. The following topics are discussed in detail:

- Photon statistics and photodetection of quantum light
- Fundamental ideas of field quantization, Fock states, and single-mode and multi-mode quantum states
- Coherent states and phase space representations of light
- Beam splitters and interferometers in quantum optics, Hong-Ou Mandel interference
- Non-classical light, single-photon states, squeezed states, homodyne detection
- Correlation functions and quantum coherence, Hanbury-Brown Twiss experiments

5 Learning outcomes / competencies:

Mastery of the fundamental concepts of quantum optics, including knowledge of specific phenomena that distinguish quantum optical observation from classical experiments.

The students

- are familiar with the concepts of quantum optics and can link them to experimental setups,
- are able to use computational methods from quantum mechanics to solve practical problems in experimental quantum optics,
- can distinguish quantum optical observations from purely classical optical experiments,
- understand the principle of field quantization and its implications for the definition of a photon and the formally correct description of wave-particle duality,
- understand the modeling of "classical" laser light and the significance of photon statistics,
- are proficient in calculating quantum interference in various setups,
- can assess the applicability of non-classical light states in practice.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Optoelectronics and Photonics.
12	**Module coordinator:** Prof. Dr. Christine Silberhorn, Prof. Dr. Tim Bartley
13	**Other information:** None

Physics Project Practicum

Laboratory Course

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
1d	180	6	1st–2nd	Every semester	1	en	WP

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Physics project internship	P	60	12	WP	4 (two groups supervised in parallel)

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

The practical course comprises experiments in the fields of optoelectronics, photonics, and materials science. Students select four experiments from a list of topics announced via the Campus Management System. Experiments on the following topics are possible: Ellipsometry and angle-resolved optical analysis, waveguide characterization, parametric photon pair sources, diode-pumped solid-state lasers with frequency doubling, optical length measurement, characterization of optoelectronic components: LED lasers, nonlinear optics on the computer, photodetectors, optical communications and high-frequency technology, electromagnetic field simulations, modern light sources, correlated microscopy, etc.

5 Learning outcomes / competencies:

Introduction to independent work and experimentation through small research-related projects with clearly defined tasks. The experiments to be carried out are designed to include a significant amount of independent experimentation and setup. This bridges the gap between the typical experiments in the advanced practical course in the Bachelor's program in Physics, which are still largely carried out under very detailed guidance with ready-made equipment, and the scientific work required in the modules of the research phase and the Master's thesis. The experiments offered are designed to go well beyond typical textbook topics and effects and to include application-related aspects that are considered professionally qualifying for later work in a research-related professional environment in the field of physics.

Students

- learn to work and experiment independently by working on small research-related projects with clearly defined tasks,
- learn how to use modern, complex physical experimental methods in a real research environment of a working group,
- learn how to use scientific literature in English, both to prepare for the various experiments and to document the results obtained in the style of a scientific publication,
- can explain scientific results obtained in the context of current research.

6	**Examination performance:** [x] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

Examination format	Examination format	Duration or scope	Weighting for the module grade
a)	Portfolio	4 attempts	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** Attendance on the days of the experiment is a prerequisite for participation.
9	**Requirements for the awarding of credit points:** Credit points are awarded upon passing the final module exam.
10	**Weighting for overall grade:** The module is weighted according to the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Optoelectronics and Photonics and in the Master's program in Materials Science.
12	**Module coordinator:** Prof. Dr. Christine Silberhorn, Prof. Dr. Jörg Lindner
13	**Other information:** None

Semiconductor Heterostructures: Fundamentals and Applications

Semiconductor Heterostructures: Fundamentals and Applications

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
01e	180	6	1	WS	1	en	WP

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Physics and application of semiconductor heterostructures	V	30	60	WP	up to 30
b)	Physics and application of semiconductor heterostructures	Ü	30	60	WP	up to 30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Fundamentals of low-dimensional HL systems (quantization energy, state densities, Fermi energies, wave functions, etc.)
- Electronic properties of semiconductor heterostructures
- Optical properties of semiconductor heterostructures
- Material systems, manufacturing methods, components

5 Learning outcomes / competencies:

Mastery of the fundamental concepts in the field of semiconductor heterostructures, including aspects of manufacturing and electrical and optical properties.

Students

- have a comprehensive qualitative understanding of semiconductor heterostructures,
- have knowledge of the fundamentals of quantitative description of the relevant phenomena,
- have the ability to apply what they have learned to problems in the field of semiconductor heterostructures, discuss the results, and classify them in relation to the subject area.

6 Examination:

[X] Module final examination (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min. 30–45 min.	100%

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Materials Science master's program.
12	**Module coordinator:** Prof. Dr. Dirk Reuter, Prof. Dr. Donat As
13	**Additional information:** Knowledge of solid-state and semiconductor physics is desirable

Quantum Mechanics II

Quantum Mechanics II

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
2	240	8	1	Every winter semester	1	German/English	P

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Quantum Mechanics II	V	60	75	P	30
b)	Quantum Mechanics II	Ü	30	75	P	30

2 **Options within the module:**

None

3 **Participation requirements:**

None

4 **Contents:**

- CGS unit system, axioms of quantum mechanics
- Stationary and time-dependent perturbation theory
- Electromagnetic fields in quantum mechanics
- Electron spin
- Elements of relativistic quantum mechanics
- Path integral formulation of quantum mechanics and Green's functions
- Many-particle systems and fundamentals of quantum field theory

5 **Learning outcomes / competencies:**

Familiarity with advanced concepts of quantum mechanics, mastery of the relevant calculation methods, and in-depth understanding of the interconnections with other subfields of theoretical physics.

Students

- have a practical understanding of stationary and time-dependent perturbation theory,
- are able to model quantum mechanical particles in electromagnetic fields,
- have mastered the practical use of spinors and spin operators,
- are familiar with various quantum mechanical equations of motion (Schrödinger, Pauli, Klein-Gordon, Dirac) and understand their areas of application and limiting cases,
- have a physical understanding of important relativistic phenomena and effects such as the Klein paradox, Rashba effect, and jitter motion,
- have the ability to describe quantum mechanical systems using propagators or Green's functions,
- understand the description of quantum mechanical many-particle systems in occupation number formalism and using field operators, and can apply these concepts to simple example systems.

6 Examination:

[X] Module final exam (MAP) [] Module exam (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7 Coursework / qualified participation:

to	Form	Duration or scope	SL / QT
b)	Exercises		QT

8 Requirements for participation in examinations:

Qualified participation in the exercise is a prerequisite for participation in the final module examination.

9 Requirements for the awarding of credit points:

Credit points are awarded upon passing the final module examination.

10 Weighting for overall grade:

The module is weighted by the number of credit points (factor: 1).

11 Use of the module in other degree programs:

None

12 Module coordinator:

Prof. Dr. Wolf Gero Schmidt, Prof. Dr. Arno Schindlmayr

13 Other information:

None

Module group Specialization

Atomistic Materials Modeling

Atomistic Materials Modeling

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
3a	180	6	1	Every winter semester	1	German/English	WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Atomistic Materials Modeling	V	30	60	WP	30
b)	Atomistic Materials Modeling	Ü	30	60	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Empirical potentials and force fields
- Electronic exchange and correlation interactions
- Density functional theory
- Wave function-based methods
- Fundamental theorems and pseudopotentials
- Calculation of structural and vibrational properties and thermodynamic quantities

5 Learning outcomes / competencies:

Ability to independently perform atomic-scale material simulation using standard methods of theoretical material physics:

Students

- understand the basic methods of atomistic material simulation and their areas of application and limitations, are familiar with the relevant nomenclature,
- are able to identify suitable methods for structural analysis of molecules, solids, and nanostructures,
- are proficient in common program packages for atomistic structure elucidation, such as Gaussian and Quantum Espresso, including the determination of meaningful numerical parameters and basis sets,
- have the ability to discuss and evaluate the calculated results in comparison with data from the original literature.

6 Examination:

[X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** none
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Materials Science master's program.
12	**Module coordinator:** Prof. Dr. Wolf Gero Schmidt, Prof. Dr. Arno Schindlmayr
13	**Other information:** None

Computational Optoelectronics and Photonics I

Computational Optoelectronics and Photonics I

Module No.:	Workload (h):	LP:	Semester of study:	Rotation:	Duration (in semesters):	Language:	P/WP:
3b	180	6	1	Every winter semester	1	en	WP

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Computational Optoelectronics and Photonics I	V	30	60	WP	30
b)	Computational Optoelectronics and Photonics I	Ü	30	60	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Application-oriented introduction to the practical numerical implementation of mathematical problems and the graphical presentation of calculated data
- Light propagation in nanostructured solids
- Quantum mechanical oscillator in an optical resonator
- Excitons in low-dimensional semiconductor systems coupled to propagating light fields
- Localized electronic states and their properties in nanostructures
- Simple models for quantum optics and quantum information

5 Learning outcomes / competencies:

Students

- acquire a fundamental understanding of nanostructured solids and their use in photonic structures based on concrete examples.
- can numerically implement the relevant equations in abstract form based on the mathematical description of physical systems,
- are able to develop program codes under supervision and use software packages to numerically analyze the issues covered in the lecture,
- are able to numerically implement and analyze nonlinear systems of equations under supervision,
- can graphically represent complex physical phenomena and present the results in a meaningful way.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Optoelectronics and Photonics.
12	**Module coordinator:** Prof. Dr. Stefan Schumacher, Dr. Matthias Reichelt
13	**Other information:** None

Computational Optoelectronics and Photonics II

Computational Optoelectronics and Photonics II

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
3c	180	6	2	SS	1	German / English	WP

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Computational Optoelectronics and Photonics II	V	30	60	WP	30
b)	Computational Optoelectronics and Photonics II	Ü	30	60	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Application of many-particle methods to nanostructured photonic systems
- Numerical analysis of electronic states in low-dimensional structures
- Numerical analysis of optical nonlinearities in low-dimensional structures
- Light propagation coupled to nonlinear optical excitations in the medium
- Applications of nonlinear optical propagation effects such as bistability and solitons

5 Learning outcomes / competencies:

Students

- build on the module Computational Optoelectronics I to deepen their understanding of nanostructured solids and their use in photonic structures using concrete examples.
- have the ability to apply many-particle methods to nanostructured solid-state systems and to evaluate the resulting equations numerically,
- have the ability to numerically calculate the nonlinear optical excitation behavior of nanostructured solid-state systems,
- be able to independently implement mathematical formulations of physical model systems numerically,
- can independently develop program codes to numerically analyze the content covered.

6 Examination:

[X] Module final examination (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written exam or oral exam	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Optoelectronics and Photonics.
12	**Module coordinator:** Prof. Dr. Stefan Schumacher, Dr. Matthias Reichelt
13	**Other information:** None

Integrated Optics and Photonics

Integrated Optics and Photonics

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
3d	180	6	2	SS	1	German/English	WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Integrated Optics and Photonics	V	30	60	WP	30
b)	Integrated Optics and Photonics	Ü	30	60	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Propagation of electromagnetic waves in optical waveguides (wave equation, boundary conditions, and mode dispersion relations for planar waveguides)
- Selected materials and manufacturing processes (ion exchange in glasses and crystals, diffusion waveguides in $LiNbO_3$, epitaxially grown waveguides in semiconductor materials)
- Theory of coupled modes (description with eigenmodes of the undisturbed system, description with local normal modes of the real system)
- Electro-optical components (electro-optical effect in dielectric crystals, modulators, and switches)
- Nonlinear optical components

5 Learning outcomes / competencies:

Students will learn the basic concepts of integrated optics and photonics and their applications.

Students

- will be able to identify and analyze issues in the field of integrated optics and distinguish them from conventional classical optics.
- can quantitatively describe wave propagation in guided structures and independently apply this description (approximately) to a wide variety of waveguide geometries,
- be able to describe the functional principle of integrated optical components based on the physical fundamentals and independently perform analytical or numerical modeling of simple components using methods of coupled mode theory,
- can independently analyze more complex integrated optical structures, identify their functional components, and describe their function,
- can independently study current English-language specialist literature on the subject of integrated optical components and photonic structures.

6	**Examination:** [X] Module final examination (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted according to the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Optoelectronics and Photonics.
12	**Module coordinator:** Prof. Dr. Christine Silberhorn, Prof. Dr. Tim Bartley
13	**Other information:** None

Ion beam analysis

Ion Beam Analysis

Module no.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
3e	180	6	1	WS	1	German/English	WP

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Ion beam analysis	V	15	30	WP	30
b)	Ion beam analysis	P	30	60	WP	up to 5
c)	Ion beam analysis	S	15	30	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

This block course, conducted in collaboration with Ruhr University Bochum at the RUBION accelerator laboratory, introduces the fundamentals of nuclear solid-state physics and applications of accelerator physics.

a) Lecture: Fundamentals of ion-solid interactions and their application to material analysis and modification, in particular:

- ion sources, ion optics, accelerator principles
- Interaction of ionizing radiation with biological organisms, radiation protection
- Solid-state thin-film analysis using Rutherford backscattering spectroscopy (RBS)
- Trace element analysis using nuclear reaction analysis (NRA)
- Element detection using particle-induced X-ray emission (PIXE)
- Ion-solid interaction, ion ranges, defect formation
- Doping of semiconductors using ion implantation
- Application of particle accelerators in astrophysics, geophysics, nuclear physics, and medical physics
- Nanostructuring and analysis with ion beams

b) Practical training: Production and examination of samples using the particle accelerators available at RUBION as part of projects related to the lecture material.

c) Seminar: Presentation of experimental results and their theoretical background.

5 Learning outcomes / competencies:

Students

- have mastered the fundamental principles of particle accelerators and the experiments carried out using them, the basic concepts of ion-solid interaction and the applications based on these concepts in the field of nuclear solid-state analysis and ion beam modification of surfaces,
- are familiar with beam time operation at a large research facility,

	▪ can independently plan experiments for ion beam analysis and modification of materials, carry them out in cooperation with the operators of a particle accelerator, and evaluate the results, in some cases using suitable software packages, ▪ can apply the methods they have learned to analogous problems and, based on their experience, classify and critically evaluate the results presented in the specialist literature, ▪ have experience in web-based collaboration in inter-university teams.
6	**Examination:** [] Module final exam (MAP) [x] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
b)-c)	Written assignment with final presentation	Approx. 30 pages Approx. 30 min.	100

7	**Coursework / qualified participation:** none
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Materials Science master's program.
12	**Module coordinator:** Prof. Dr. Jörg Lindner
13	**Additional information:** Due to the extensive preparations required for the experimental part at the particle accelerator and the limited number of places available, it is necessary to consult the module coordinator at an early stage.

Microscopy and spectroscopy with electrons

Microscopy and Spectroscopy with Electrons

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
3f	180	6	2	SS	1	German/English	WP

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Microscopy and spectroscopy with electrons	V	30	60	WP	30
b)	Microscopy and spectroscopy with electrons	Ü	30	60	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

This module covers the fundamentals of transmission electron microscopy in its entirety and explains its application for characterizing materials on the nano and sub-nanometer scale.

- Electron-optical components and beam paths in (scanning) transmission electron microscopes (S)TEM
- Electron microscopic preparation methods
- Imaging techniques and contrast types
- Electron diffraction for phase analysis
- Electron-solid interaction
- Kinematic and dynamic theory of electron diffraction
- Conventional electron microscopy and lattice defects
- Contrast transfer and high resolution
- Energy dispersive X-ray spectroscopy EDS
- Electron energy loss spectroscopy EELS in TEM and STEM
- Spectroscopy of inter- and intraband transitions and plasmons
- Energy-filtered transmission electron microscopy (EFTEM)
- Further methods

5 Learning outcomes / competencies:

The aim of this module is to provide a comprehensive understanding of the methodological possibilities of modern transmission electron microscopes for structural analysis of materials against the background of quantum mechanical calculations of the interaction between electron waves and condensed matter.

Students

- understand the propagation of an electron wave in crystalline materials with and without crystal defects, as well as the transport of an electron beam through the microscope from the electron source to the detector.
- are able to select the appropriate beam paths and investigation methods for the investigation of various problems and to interpret the image contrasts generated in this way,

	▪ have the ability to evaluate simple electron diffraction diagrams, ▪ are able to interpret TEM images reproduced in technical literature with regard to the underlying real structure, ▪ are able to understand the information contained in EELS and EDS spectra about the atomic composition and electronic structure of solids, ▪ can use standard electron microscopy programs.
6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

to	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Materials Science master's program.
12	**Module coordinator:** Prof. Dr. Jörg Lindner
13	**Other information:** None

Photonic nanostructures

Photonic Nanostructures

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
3g	180	6	2	SS	1	German/English	WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Photonic nanostructures	V	30	60	WP	30
b)	Photonic nanostructures	Ü	30	60	WP	30

2 **Options within the module:**

None

3 **Participation requirements:**

None

4 **Contents:**

- Light-matter interaction (Maxwell's equations in matter, wave equation and Helmholtz equation, optical response of materials, polarization field, dielectric function of insulators, semiconductors, and metals)
- Photonic nanostructures (one-dimensional periodicity: Bragg reflectors, transfer matrix algorithm; optical resonators I: micropillar resonators; optical resonators II: microdisks and ring resonators, electromagnetic fields in periodic media, symmetries and photonics, photonic crystal membranes; optical resonators III: defects in photonic crystals)
- Plasmonic nanostructures (boundary and surface plasmon polaritons, metallic nanoparticles, optical metamaterials)

5 **Learning outcomes / competencies:**

Students should be able to apply the fundamental concepts of light interaction with nanostructures correctly and soundly to current problems in modern physics and to develop solutions independently.

Students

- will be able to independently identify and differentiate issues in the field of nano-optics and distinguish them from optics in macroscopic objects.
- have the ability to describe and evaluate effects that occur when light interacts with dielectric and metallic nanostructures,
- can independently develop solutions to more complex problems involving optical nanostructures and justify them using the knowledge they have acquired,
- can develop and justify meaningful analytical and numerical approximation methods for solving problems in the field of nanophotonics under guidance,
- have the ability to independently engage with current English-language specialist literature on the subject of nano-optics.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

to	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** MSc Optoelectronics & Photonics, MSc Chemistry, MSc Materials Science
12	**Module coordinator:** Prof. Dr. Cedrik Meier
13	**Other information:** None

Quantum Electronics

Quantum Electronics

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
3	180	6	2	SS	1	German/English	WP

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Quantum electronics	V	30	60	WP	30
b)	Quantum electronics	Ü	30	60	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

Fundamental concepts of quantum electronics, their optical, electrical, and optoelectronic principles, and their applications. Understanding and mathematical formulation of physical phenomena and models.

- Experimental approach to quantum systems
- Atoms and quantum structures as two-level systems
- Coherent light-matter interaction
- Solid-state quantum bits
- Semiconductor quantum dots
- Quantum bits in strong optical fields and resonators
- Functional structures and applications

5 Learning outcomes / competencies:

Students

- have in-depth knowledge in the field of quantum electronics,
- have in-depth knowledge of two-level systems,
- have in-depth knowledge of light-matter interaction in strong fields,
- are able to describe the laws of physics mathematically,
- are able to derive fundamental laws of quantum electronics,
- can clearly communicate the physical and technical fundamentals and applications of quantum electronics.

6 Examination:

[X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

to	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Optoelectronics and Photonics.
12	**Module coordinator:** Prof. Dr. Klaus Jöns, Prof. Dr. Christine Silberhorn
13	**Other information:** None

Quantum Communication and Quantum Information Processing

Quantum Communication and Information

Module	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
3i	180	6	2	SS	1	German	WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Quantum communication and quantum information processing	V	30	60	WP	30
b)	Quantum communication and quantum information processing	Ü	30	60	WP	30

2 **Options within the module:**

None

3 **Participation requirements:**

None

4 **Contents:**

This module teaches the basic concepts and protocols of quantum communication and quantum information processing.

- Introduction to the fundamentals of quantum information (mathematical formulation of the concept of information, axioms of quantum mechanics)
- Qubits and quantum measurements
- Entangled systems, no-cloning theorem, entangled states, Bell inequalities
- Quantum cryptography (protocols, experimental implementations, security proofs, and eavesdropping attacks)
- Quantum teleportation, quantum gates, quantum dense coding (protocols and implementation)
- Entanglement distillation and quantum repeaters

5 **Learning outcomes / competencies:**

Mastery of the fundamental concepts of quantum communication, including knowledge of important protocols and their practical implementations.

The students

- are capable of working in an interdisciplinary manner and acquiring fundamental knowledge from other fields,
- are familiar with abstract concepts from information theory and quantum physics and can demonstrate their connection in relevant physical experiments,
- have internalized the fundamental idea behind novel quantum technologies, which is to harness genuine quantum physical properties for practical applications,
- understand the principle of entangled states and its significance for the modern interpretation of quantum physics,
- are familiar with the basic protocols of quantum communication and quantum information processing,
- can familiarize themselves with current research topics that are only partially covered in textbooks, thus finding a starting point for independent research work,
- can realistically assess the opportunities and limitations of future technologies.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** none
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Optoelectronics and Photonics.
12	**Module coordinator:** Prof. Dr. Christine Silberhorn
13	**Other information:** None

Spintronics

Spintronics

Module no.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
3j	180	6	2	SS	1	German	WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Spintronics	V	30	60	WP	30
b)	Spintronics	Ü	30	60	WP	30

2 **Options within the module:**

None

3 **Participation requirements:**

None

4 **Contents:**

- Quantum mechanical description of spin: Spin-Pauli matrices, density matrix, Bloch sphere
- Spin dynamics and Rabi formula, spin relaxation and dephasing
- Spectroscopy of spins: NMR, EPR, ENDOR, EDMR, STM-EPR
- Writing and reading qubits (spin injection and spectroscopy)
- Passive components in magnetoelectronics: GMR, TMR, MRAM
- Active components: Spin field effect transistor
- Fundamentals of spin-based quantum information

5 **Learning outcomes / competencies:**

Students should be able to understand fundamental concepts of spin physics, in particular spin dynamics, and apply them to describe spin-based components against the background of the interaction between experiment and theory.

Students

- have a command of the quantum mechanical fundamentals of spin physics, in particular spin dynamics,
- are aware of the conceptual differences that arise in the description of quantum mechanical ensembles and individual spins,
- have detailed knowledge of measurement methods based on spin interactions and their multidisciplinary application in biology, chemistry, physics, and medicine, as well as their use for readout of spin-based quantum bits ("qubits"),
- can analyze questions on the general topic of spin-based electronics and apply the mathematical models developed to specific components,
- are familiar with the physical properties and special features of spin-based qubits and can place them in a larger context (electronics, computer science, quantum information).

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** None
12	**Module coordinator:** Prof. Dr. Uwe Gerstmann
13	**Other information:** None

Computational Spectroscopy

Computational Spectroscopy

Module No.:	Workload (h):	LP:	Semesters of study:	Rotation:	Duration (in semesters):	Language:	P/WP:
3k	180	6	2	SS	1	German	WP

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Computational Spectroscopy	V	30	60	WP	30
b)	Computational Spectroscopy	Ü	30	60	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- General fundamentals: Time-dependent perturbation theory, Fermi's golden rule, linear response theory
- Overview of spectroscopic techniques: linear and nonlinear optical spectroscopy, core-level spectroscopy, X-ray absorption, magnetic resonance, infrared and Raman spectroscopy
- Modern methods for calculating spectroscopic properties: time-dependent density functional theory, constrained density functional theory, wave function-based methods

5 Learning outcomes / competencies:

Students should be able to understand the basic concepts of computer-aided calculation (simulation) of spectroscopic material properties, apply methods for numerical prediction, and compare these with experimental measurement results.

Students

- can identify and analyze materials science issues related to spectroscopy,
- are aware that modern spectroscopic experiments can often only be fully evaluated with the help of theoretical reference values,
- are familiar with the fundamental quantum mechanical strategies and technical concepts necessary for the atomistic description of materials and the prediction of their spectroscopic properties on a computer,
- can select an adequate level of approximation for given atomistic structures (taking into account computational effort and accuracy) and apply it to selected questions,
- are able to discuss the theoretical results obtained in the context of experimental data and establish cross-connections to current research questions in materials science.

6	**Examination:** [X] Module final exam (MAP) [] Module exam (MP) [] Module partial examinations (MTP) **zu** / **Examination format** / **Duration or scope** / **Weighting for the module grade** a)-b) / Written or oral examination / 120–180 min, 30–45 min / 100 The respective instructor will announce how the examination is to be completed in concrete terms no later than the first three weeks of the lecture period.
7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Materials Science master's program.
12	**Module coordinator:** Dr. Uwe Gerstmann, Prof. Dr. Arno Schindlmayr
13	**Other information:** None

zu	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

Semiconductor epitaxy

Semiconductor Epitaxy

Module number:	Workload (h):	Credits:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
3l	180	6	2	SS	1	en	WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a	Semiconductor Epitaxy	V	30	60	WP	up to 30
b	Semiconductor Epitaxy	Ü	30	60	WP	up to 30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- **Fundamentals**
  - Fundamentals of crystal structure
  - Elastic properties of heterostructures
  - Dislocations
- **Thermodynamics of layer growth**
  - Equilibrium states
  - Crystal growth
- **Atomistic aspects of layer growth**
  - Surface structure
  - Kinetic processes in layer growth
  - Self-organized nanostructures
- **Methods of semiconductor epitaxy**
  - Molecular beam epitaxy (MBE)
  - Metal organic chemical vapor deposition (MOCVD)
- **Characterization methods**
  - In-situ analysis methods (RHEED, etc.)

5 Learning outcomes / skills:

Students will acquire:

Technical skills:

Lecture: Mastery of the fundamental concepts of semiconductor epitaxy, including aspects of production, properties, and characterization. Understanding and, where applicable, mathematical formulation of physical facts and models.

Exercises: Practical work on problems in the field of semiconductor epitaxy, applying the knowledge acquired in the lecture. Students should identify problems, establish links to the lecture, formulate problems mathematically where appropriate, discuss results, and place them in an overall physical context.

Interdisciplinary skills:

- Ability to think conceptually, analytically, and logically, and the ability to apply acquired knowledge in various fields of semiconductor nanostructure physics
- Ability to apply the problem-solving strategies learned in an interdisciplinary manner
- Presentation skills through the presentation of problem solutions within the framework of the exercise
- Ability to deepen acquired skills through self-study.
- Teamwork skills through working on problems in small groups

6 Examination:

[x] Module final exam (MAP) [] Module exam (MP) [] Module partial examinations (MTP)

to	Examination	Duration or scope	Weighting for the module grade
a)-b)	Written or oral exam	120-180 min 30-45 min	100

The respective instructor will announce how the examination is to be taken no later than the first three weeks of the lecture period.

7 Coursework/qualified participation:

None

8 Requirements for participation in examinations:

None

9 Requirements for awarding credits:

Credits are awarded once the final module examination has been passed.

10 Weighting for overall grade:

The module is weighted by the number of credits it carries (factor: 1).

11 Use of the module in other degree programs:

None

12 Module coordinator:

Prof. Dr. D. Reuter, Prof. Dr. D. As

13 Other information:

Basic knowledge of solid state physics and semiconductor physics is recommended.

Recommended reading:

“Epitxaxy of Semiconductors,” Udo W. Pohl (Springer Heidelberg 2013)

Optoelectronic semiconductor devices

Optoelectronic Semiconductor Devices

Module number:	**Workload (h):**	**Credits:**	**Semester:**	**Rotation:**	**Duration (in semesters):**	**Language:**	**P/WP:**
3m	180	6	1	WS	1	en	WP

1 Module structure:

	Course	**Teaching format**	**Contact hours (h)**	**Self-study (h)**	**Status (P/WP)**	**Group size (participants)**
a)	Optoelectronic semiconductor devices	V	30	60	WP	up to 30
b)	Optoelectronic semiconductor devices	Ü	30	60	WP	up to 30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

The first part of the lecture provides an overview of the physics of light-emitting diodes and the static properties of semiconductor lasers, starting with the fundamentals of solid-state physics and continuing with the design and operation of the most important semiconductor LEDs and laser diodes. The second part deals with the dynamic properties of semiconductor lasers, their spectral properties, and the fundamentals of various semiconductor photodetectors.

- Significance of optoelectronic semiconductor devices
- Light-emitting diodes – LEDs
- Laser diodes – static properties
- Laser diodes – dynamic properties
- Optoelectronic detectors

5 Learning outcomes / competencies:

Students should be able to understand the basic concepts of optoelectronic semiconductor devices and apply them independently to problem solving.

Students

- have a sound basic knowledge of light-emitting semiconductor devices such as LEDs and laser diodes,
- have a physical understanding of the static, dynamic, and spectral properties of LEDs and semiconductor lasers,
- be able to apply basic knowledge of the influence of quantum structures on the properties of modern optoelectronic semiconductor devices,
- have the ability to apply this knowledge in the design and operation of optoelectronic semiconductor devices,
- have fundamental knowledge of the functioning and applicability of various semiconductor photodetectors.

6	**Examination:** [x] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

to	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral exam	120-180 min. or 30-45 min.	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credits:** Credits are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credits it carries (factor: 1).
11	**Use of the module in other degree programs:** None
12	**Module coordinator:** Prof. Dr. D. Reuter, Prof. Dr. D. As
13	**Other information:** Basic knowledge of solid state physics and semiconductor physics is recommended.

Introduction to Quantum Computing

Introduction to Quantum Computation

Module number:	Workload (h):	Credits:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
3n	180	6	2	SS	1	en	WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Introduction to Quantum Computation	V3Ü2	75	105	WP	40

2 **Options within the module:**
None

3 **Participation requirements:**
None

4 **Contents:**
This lecture introduces the fundamental concepts of quantum computing and information from the perspective of computer science. This includes an introduction to quantum mechanics, quantum entanglement, quantum algorithms, quantum error correction, and quantum information theory.

- Quantum Mechanics
- Quantum entanglement
- Quantum algorithms
- Quantum error correction
- Quantum information

5 **Learning outcomes / Competencies:**

Students will be able to:

- describe and apply the postulates of quantum mechanics
- understand the use of entanglement as a resource
- design and analyze basic quantum algorithms
- apply the theory of error-correcting codes
- understand and apply fundamental concepts of quantum information theory, such as entropy Non-cognitive

skills:

- Learning skills
- Self-observation

6 **Examination:**

[x] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

on	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral exam	120-180 min 30-45 min	100

7 **Coursework / qualified participation:**

to	Examination	Duration or scope	SL/QT
a)	Exercise tasks		QT

8	**Requirements for participation in examinations:** Proof of qualified participation in the module course is required in order to take the final module exam.
9	**Requirements for the awarding of credits:** Credits are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted according to the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** MSc Computer Science
12	**Module coordinator:** Prof. Dr. Sevag Gharibian
13	**Additional information:** Basic knowledge of linear algebra and algorithms is recommended. **Implementation method** Slides and blackboard writing. All important concepts and techniques are further deepened with examples in exercises. **Learning material, literature** • Michael A. Nielsen, Isaac L. Chuang, Quantum Computation and Quantum Information, Cambridge University Press • Lecture slides, exercises

Data science for dynamic systems

Data science for dynamical systems

Module number:	Workload (h):	Credits:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
3o	180	6	1	WS	1	en	WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Data science for dynamical systems	V	30	60	WP	50
b)	Data science for dynamical systems	Ü	30	60	WP	25

2 **Options within the module:**

None

3 **Participation requirements:**

None

4 **Contents:**

This course has a modular structure and is offered on an interdisciplinary basis for various degree programs and faculties. The content will be tailored to the specific degree program depending on the prior knowledge of the participants. Overarching core topics include

- Fundamentals of modeling dynamic systems using differential and difference equation models
- Data-driven identification methods for linear models based on the least squares approach
- Data-driven identification methods for nonlinear models (e.g., artificial neural networks)
- Learning from data-driven models incorporating a priori system knowledge
- Identification of underlying model structure equations (topology selection), e.g., by means of regularization or hypothesis testing with regard to competing target criteria
- (Data-driven) model reduction
- Manipulation of available model input data (dimension reduction and augmentation methods), e.g., autoencoders, principal component analysis, and kernel methods
- Statistical evaluation of the available input and output data of dynamic systems and corresponding methods for system excitation
- Statistical evaluation of the achieved model quality (overfitting vs. underfitting) using cross-validation In addition to imparting methodological knowledge, extensive programming and simulation exercises are carried out using modern software programs (especially in the Julia programming language)

. A wide range of practical application examples from various domains (e.g., engineering, natural sciences, and economics) round off the course.

5 **Learning outcomes / competencies:**

After completing the course, participants will be able to

- describe and apply methods for identifying dynamic systems,
- critically evaluate identification results,
- understand and analyze complex data-driven modeling tasks in interdisciplinary teams, derive effective solution methods, and evaluate independently developed results.

6	**Examination:** [x] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

to	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral exam	120-180 min 30-45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credits:** Credits are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credits it carries (factor: 1).
11	**Use of the module in other degree programs:** MSc Computer Science
12	**Module coordinator:** Dr. Oliver Wallscheid, Assistant Professor Sebastian Peitz
13	**Other information:** None

Advanced seminar

Advanced Seminar

Module No.: 04	Workload (h): 120	LP: 4	Semester: 1st– 2nd	Cycle: Every semester	Duration (in semesters): 2	Language: en/de	P/WP: P

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Lectures on experimental physics	S	30	30	WP	up to 20
b)	Lectures on theoretical physics	S	30	30	WP	up to 20
c)	Event physics	S	45	15	WP	up to 3

2 Options within the module:

Two courses must be selected from courses a) to c).

3 Participation requirements:

None

4 Contents:

In (a) and (b), students are instructed to address current topics in the field of modern physics, explore them in depth, and finally present them in the form of their own presentation as part of the course. This opportunity to present their own work is intended to serve both as subject-specific training in current areas of research and as a means of developing personal presentation skills.

In (c), students are instructed to first optimize the experiments developed in GP II for presentation purposes, develop popular scientific explanations, create illustrative material, and develop an exciting and educational form of communication. Presenting to a large audience unfamiliar with the subject matter offers an opportunity to further develop communication skills.

5 Learning outcomes / skills:

Students

- can independently prepare and deepen their knowledge of a given topic through their own studies and literature research,
- are able to recognize and formulate the relevance of the topic to related subfields,
- can prepare their presentation according to didactic and technical criteria in a manner appropriate to the target audience,
- use the experience gained to further develop their own presentation skills and their ability to engage in dialogue when answering scientific questions.

6 Examination:

[] Module final exam (MAP) [] Module examination (MP) [X] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
First selected course from courses a) to c) offered	Presentation	approx. 30 min.	50
Second selected course from	Presentation	approx. 30 min.	50

	courses offered a) to c)			

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credits:** Credits are awarded once the module exams have been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credits it carries (factor: 1).
11	**Use of the module in other degree programs:** None
12	**Module coordinator:** Prof. Dr. Cedrik Meier, Prof. Dr. Torsten Meier
13	**Other information:** None

Technical English II

English for Technical Purposes II

Module number:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
05	180	6	1st–2nd	Every semester	2	en	P/WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	English Oral Skills for Students of Natural Sciences	Ü	30	60	P	up to 20
b)	English for Professional and Study Abroad Purposes	Ü	30	60	WP	up to 20

2 Options within the module:

None

3 Participation requirements:

The prerequisite for participation is proof of the necessary prior knowledge at level B2.1.

4 Contents:

English Oral Skills for Students of Natural Sciences:

This course is aimed at students of natural sciences who wish to expand their existing knowledge of lecture and presentation strategies and improve their communication skills in relation to their studies and future professional activities. Practical exercises help students to deepen the theoretical knowledge imparted in the course and apply it in their own presentations in English.

English for Profession and Study Abroad:

This course is specifically designed for students who want to develop their written and oral English language skills with a view to pursuing an internationally oriented career or planning a stay abroad. The course covers the following topics:

- Telephone conversations and writing emails in English
- Writing resumes and job applications
- Conversation and presentation strategies
- Living abroad

The correct use of English grammar and the expansion of vocabulary are equally important here.

5 Learning outcomes / skills:

Participants will expand both their general and subject-specific English vocabulary. They will be able to conduct technical pro/con discussions, present research topics orally and in writing in correct English, write longer structured technical texts such as theses or scientific articles, and communicate appropriately in a professional context, both orally and in writing. The courses are based on level B2 of the Common European Framework of Reference.

	Students ▪ have the ability to write scientific publications for the English-speaking world using appropriate vocabulary and correct grammar, ▪ can independently design English-language presentations and communicate research results in scientific lectures, ▪ have the ability to present specialist topics and their own point of view clearly and in detail in English.
6	**Examination:** [] Module final exam (MAP) [] Module examination (MP) [X] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)	Oral examination	Approx. 30 min.	50%
b)	Written assignment or oral exam	approx. 500 words approx. 15 min.	50

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** Regular attendance at the two language courses (maximum of three absences) is a prerequisite for participation.
9	**Requirements for the awarding of credit points:** Credit points are awarded once all module exams have been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** None
12	**Module coordinator:** Dr. Sigrid Behrent
13	**Other information:** None

Module group Theoretical Physics

Group theory

Group theory

Module no.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
6a	180	6	2	SS	1	en/de	WP

1

	Course	Teaching format	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Group theory	V	30	60	WP	30
b)	Group theory	Ü	30	60	WP	30

2 **Options within the module:**

None

3 **Participation requirements:**

None

4 This module covers the essential elements and concepts of group theory for finite discrete symmetry groups, with a special focus on point groups and space groups that are important in molecular and solid-state physics. In addition, continuous groups, rotation groups, and double groups, as well as their irreducible representations, are introduced.

- Symmetry groups, unitary matrices, and characters
- Notation systems
- Representation theory
- The point groups of solid state theory and their irreducible representations
- The irreducible representations of the translation group and the space groups
- Projection operators
- Applications: Vibrational spectra, Stark effect, band structure
- The rotation group
- Determination of eigenfunctions from their transformation properties
- Double groups, treatment of spin

5 **Learning outcomes / competencies:**

Mastery of the fundamental concepts of group theory, understanding of group-theoretical methods, and knowledge of the relevant nomenclature. Ability to apply the concepts and methods of group theory to practical problems, especially in molecular and solid-state physics.

Students

- can determine symmetry in physical questions, for example in molecules or defects in crystals,
- can find representations for the underlying point and space groups,
- can establish connections between the purely mathematical concepts of group theory and physical conditions,
- can deduce the effects of symmetry on fundamental physical properties,
- can make qualitative statements about the degeneracy of electronic or vibronic levels,

	▪ can derive qualitative statements about possible dipole transitions, ▪ can assess the effect of applied electric or magnetic fields, ▪ can recognize effects of symmetry reductions and implement them mathematically, ▪ can understand and apply the concepts of special groups, rotation groups, and double groups.
6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written exam or oral exam	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** None
12	**Module coordinator:** Prof. Dr. Wolf Gero Schmidt
13	**Other information:** None

Optics of Solid-State Systems and Nanostructures

Optics of Solid-State Systems and Nanostructures

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
6b	180	6	2	SS	1	eng or de	WP

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Optics in solids and nanostructures	V	30	60	WP	30
b)	Optics in solids and nanostructures	Ü	30	60	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Semiclassical description of light-matter interaction in solids and nanostructures
- Linear and nonlinear optical properties of two- and multi-level systems
- Optical Bloch equations
- Rabi oscillations, quantum beatings
- Theoretical description of excitation-probe and four-wave mixing experiments
- Microscopic many-body theory for optical excitations in semiconductors and nanostructures
- Semiconductor Bloch equations
- Excitons and other many-particle effects
- Relaxation and dephasing
- Self-consistent description of light propagation in solids and nanostructures; polaritons

5 Learning outcomes / competencies:

Students

- know the derivation and basic properties of the optical Bloch equations,
- can solve the optical Bloch equations using various approximation strategies and use the results to describe linear and nonlinear optical properties,
- are familiar with concepts for describing many-particle effects in semiconductor optics and can apply them to derive the semiconductor Bloch equations,
- can calculate exciton effects in linear optical spectra within the framework of the semiconductor Bloch equations and describe nonlinear optical properties approximately,
- are familiar with the fundamental physical processes that lead to the dephasing of optical polarization and to the energy relaxation of optically generated charge carrier occupations,
- are familiar with the basic concept of the self-consistent description of light propagation in solids and can use it to approximately calculate fundamental effects for simple geometries,
- are familiar with the possibilities and limitations of semiclassical many-particle theory for solid-state optics and can evaluate results from the specialist literature against this background.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

to	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Optoelectronics and Photonics.
12	**Module coordinator:** Prof. Dr. Torsten Meier, Prof. Dr. Stefan Schumacher
13	**Other information:** None

Quantum Information Theory

Quantum Information Theory

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
6c	180	6	2	SS	1	en/de	WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Quantum information theory	V	30	60	WP	30
b)	Quantum information theory	Ü	30	60	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Quantum mechanics in modern formulation (states, effects, operations, and representation theorems)
- Separability and non-separability of statistical operators
- Einstein-Podolsky-Rosen paradox
- Quantum cryptography
- Quantum computers
- Quantum teleportation

5 Learning outcomes / competencies:

Students should learn the basic concepts of quantum information theory. They should be able to understand current research and perform basic calculations themselves.

Students

- are familiar with the modern formulation of quantum mechanics,
- are familiar with the concept of separability/non-separability and can apply it to statistical operators,
- are familiar with the ideas and interpretations underlying the Einstein-Podolsky-Rosen paradox and the quantum mechanical description of entangled states,
- are familiar with the fundamental processes that form the basis for quantum cryptography, quantum computers, and quantum teleportation, and can describe the phenomena using model systems.

6 Examination:

[X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written exam or oral exam	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Optoelectronics and Photonics.
12	**Module coordinator:** Prof. Dr. Jan Sperling, Prof. Dr. Torsten Meier
13	**Other information:** None

Relativistic quantum field theory

Relativistic Quantum Field Theory

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
6d	180	6	2	SS	1	German/English	WP

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Relativistic quantum field theory	V	30	60	WP	30
b)	Relativistic quantum field theory	Ü	30	60	WP	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Fundamental concepts of relativity theory: The role of metrics
- Poincaré and Lorentz groups, relativistic invariance, gauge invariance
- Elements of relativistic quantum mechanics
- Analytical and numerical solution of the Dirac equation
- Relativistically covariant formulation of quantum mechanics and electrodynamics
- Covariant Hamilton-Lagrange formalism for fields, 2. Quantization
- General (relativistic covariant) formulation of quantum field theory
- Renormalization and Feynman diagrams
- Formulation of quantum electrodynamics
- Applications of quantum electrodynamics, radiation corrections

5 Learning outcomes / competencies:

Students should be able to understand the basic concepts of relativistic quantum field theory and apply its methods in a wide range of subfields, from a relativistic description of simple atomic systems to complex questions in quantum electrodynamics.

Students

- have an overview of the areas of quantum mechanics in which relativistic effects play a central role,
- are familiar with methods for the analytical and numerical solution of the Dirac equation and can apply these to simple systems (e.g., individual atoms),
- have a clear insight into wave-particle duality, as expressed in quantum field theory,
- have mastered the theoretical foundations and methods of relativistic quantum field theory in covariant formulation and have acquired an in-depth understanding of the interaction between (relativistic) quantum mechanics, electrodynamics, and (classical) Hamiltonian mechanics,
- are able to apply the knowledge acquired in the lecture to specific questions of quantum electrodynamics.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** None
12	**Module coordinator:** Prof. Dr. Jan Sperling, Prof. Dr. Uwe Gerstmann
13	**Other information:** None

Theory of Relativity

Theory of Relativity

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
6e	180	6	2	SS	1	German	WP

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Theory of relativity	V	30	60	WP	up to 240
b)	Theory of relativity	Ü	30	60	WP	up to 30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- **Newtonian mechanics (and gravitation)**
- **Limits of classical description, relativistic effects in physics**
- **Fundamentals of special relativity**:
  - 4-vectors and tensor fields, coordinate transformation, Galilean/Lorentz invariance
  - Energy-momentum tensor, length contraction, time dilation
  - Minkowski space, covariant and contravariant derivative
  - Field strength tensor, covariant formulation of Maxwell's equations
- **General theory of relativity**:
  - The strong equivalence principle
  - Curvilinear coordinates, differential geometry (connection and Christoffel symbols)
  - Einstein field equations
  - Curvature of spacetime, Schwarzschild metric, black holes
  - Robertson-Walker metric, Friedmann equations, cosmology

5 Learning outcomes / competencies:

Students should be able to understand fundamental concepts of relativity theory and apply its advanced methods to selected problems.

Students

- will gain an overview of the areas of physics in which relativistic effects play an important role,
- have mastered the theoretical foundations and methods of relativity theory,
- have a deeper understanding of the relativistically covariant formulation of physical phenomena and can apply this to selected systems,
- have a command of the fundamentals of differential geometry (metrics, connections, etc.) and can draw connections to other areas of physics,
- are familiar with methods for solving Einstein's field equations, can apply these to simple examples (e.g., black holes), and can analyze and discuss the results.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted according to the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** None
12	**Module coordinator:** Prof. Dr. Uwe Gerstmann, Dr. Matthias Reichelt
13	**Other information:** None

Theoretical Quantum Optics

Theoretical Quantum Optics

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semeste	Language:	P/WP:
6f	180	6	2	SS		German/English	WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Theoretical quantum optics	V	30	60	WP	30
b)	Theoretical quantum optics	Ü	30	60	WP	30

2 **Options within the module:**

None

3 **Participation requirements:**

None

4 **Contents:**

- Canonical field quantization
- Fock states, coherent states, squeezed light
- Statistics of light states
- Phase space functions (P, W, Q functions)
- Bunching and antibunching
- Correlation functions
- Quantum theory of light-matter interaction
- Jaynes-Cummings model, dressed states

5 **Learning outcomes / competencies:**

Students should learn basic concepts of theoretical quantum optics. They should be able to understand current research work and perform basic calculations themselves.

The students

- are familiar with the concept of photons and understand how to use photon operators,
- are familiar with the theoretical description of light states that can be generated in modern experiments,
- are familiar with the theoretical statistical interpretation of light and can thus interpret measurement results,
- are familiar with the phase space functions of the most important light states,
- are familiar with the different behavior of classical and quantized light with regard to light-matter interaction,
- are familiar with the derivation and evaluation of the Jaynes-Cummings model and can apply it to simple extended model systems.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** None
12	**Module coordinator:** Dr. Matthias Reichelt, Prof. Dr. Torsten Meier
13	**Other information:** None

Many-body theory of solids

Many-Body Theory of Solids

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semeste	Language:	P/WP:
6g	180	6	2	SS		German/English	WP

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Multiparticle theory of solids	V	30	12	P	30
b)	Multiparticle theory of solids	Ü	30		P	30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Green's functions for non-interacting electron systems
- Second quantization, Schrödinger and Heisenberg picture
- Green's functions for interacting many-particle systems
- Spectral function, functionals for ground state expectation values and excitation energies
- Perturbation theory, diagrammatic development
- Self-energy, *GW* approximation
- Quasiparticles
- Two-particle Green's function, Bethe-Salpeter equation

5 Learning outcomes / competencies:

Students should be able to understand basic concepts of quantum mechanical many-particle theory and to use common approximation methods for the quantitative calculation of electronic excitation spectra in a purposeful manner.

Students

- know the definition of the Green's function and can derive formally exact formulas for ground state expectation values and electronic excitation spectra from it.
- can understand and relate to each other various approximation strategies for the Green's function of interacting many-particle systems,
- are familiar with the concept of quasiparticles and can apply it to describe and interpret photoemission and other spectroscopic processes,
- can independently calculate excitation energies for semi-analytically solvable model systems within the framework of the GW approximation for electronic self-energy,
- can distinguish between different approximations for solving the Bethe-Salpeter equation and select a suitable method for calculating the dielectric function that correctly describes the essential aspects for specific applications,
- are familiar with the possibilities and limitations of many-body theory with regard to quantitative *ab initio* calculations and can evaluate data from the specialist literature against this background.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

to	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** None
12	**Module coordinator:** Prof. Dr. Arno Schindlmayr, Prof. Dr. Wolf Gero Schmidt
13	**Other information:** None

Preparation for the Master's Thesis: Theory

Preparation for the Master's Thesis: Theory

Module No.:	Workload (h):	LP:	Semester of study:	Cycle:	Duration (in semesters):	Language:	P/WP:
7a	45	15	3	Every semester	1	German/English	P

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Preparation of master's thesis: Theory	S	30	30	P	30
b)	Preparation of the master's thesis: Theory	P	15	105	P	15

2 Options within the module:

None

3 Participation requirements:

At least 48 LP. In the case of conditional enrollment, proof of passing the relevant exams is also required.

4 Contents:

The aim of the module is to explore the research area of the master's thesis by acquiring specific physical facts and theoretical basic knowledge under individual supervision. This includes, in particular, researching the current research literature and exchanging ideas with members of the working group in which the master's thesis is to be carried out. Depending on the chosen topic and in consultation with the supervisor, the familiarization phase may also include attending special courses, external training, or stays in cooperating working groups.

5 Learning outcomes / competencies:

Students

- can independently familiarize themselves with a new field of research and gain an overview of the current state of research,
- are able to acquire new theoretical concepts and relevant factual knowledge of physics and link these to existing knowledge,
- can systematically structure the knowledge they have acquired from various sources and summarize it in writing using consistent notation and terminology,
- can integrate themselves into a research team,
- are able to discuss scientific topics in German or English,
- can create a scientific presentation and present their own findings in the context of the current state of research,
- have learned to deal with critical questions in a scientific discussion.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

on	Examination format	Duration or scope	Weighting for the module grade
a)	Written assignment followed by presentation	approx. 10 pages approx. 25 min.	100%

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** None
12	**Module coordinator:** Prof. Dr. Cedrik Meier, Prof. Dr. Arno Schindlmayr
13	**Other information:** None

Preparation for the Master's thesis: Methodology

Preparation for the Master's Thesis: Methods

Module No.:	Workload (h):	LP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/WP:
7b	450	15	3	Every semester	1	German/English	P

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Preparation of master's thesis: Methodology	S	30	30	P	30
b)	Preparation of the master's thesis: Methodology	P	15	105	P	15

2 Options within the module:

None

3 Participation requirements:

At least 48 LP. In the case of conditional enrollment, proof of passing the relevant exams is also required.

4 Contents:

The aim of the module is to acquire the methodological knowledge and skills necessary for the master's thesis under individual supervision. In the case of a topic from experimental physics, this typically includes instruction in the safe operation of measuring equipment and the optimization of the experimental setup; in the case of a topic from theoretical physics, it includes instruction in existing computer programs and their further development for numerical simulations. In addition to guidance from members of the working group in which the master's thesis is to be carried out, depending on the chosen topic and in consultation with the supervisor, the training may also include attending special courses, external training, or stays in cooperating working groups.

5 Learning outcomes / competencies:

Students

- can familiarize themselves with the safe operation of complex measuring equipment or computer programs for scientific research purposes under supervision,
- are able to efficiently use, adjust, and optimize complex measuring equipment or computer programs for research purposes, as well as further develop individual components as needed,
- know strategies for identifying and eliminating errors and disruptions in complex measurements and numerical calculations,
- can integrate themselves into a research team,
- are able to discuss scientific topics in German or English,
- can create a scientific presentation and present their own findings in the context of the current state of research,
- have learned to deal with critical questions in scientific discussions.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a)	Written assignment followed by presentation	approx. 10 pages approx. 25 min.	100%

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module exam has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** None
12	**Module coordinator:** Prof. Dr. Cedrik Meier, Prof. Dr. Arno Schindlmayr
13	**Other information:** None

Master's thesis

Master's Thesis

Module No.:	Workload (h):	LP:	Semesters of study:	Rotation:	Duration (in semesters):	Language:	P/WP:
8	90	30	4	Every semester	1	German/English	P

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (P/WP)	Group size (participants)
a)	Written master's thesis		10	840	P	1
b)	Oral defense		1	49	P	1

2 Options within the module:

None

3 Participation requirements:

Successful completion of the modules Preparation for the Master's Thesis: Theory and Preparation for the Master's Thesis: Methodology

4 Contents:

Independent work on a research project with individual supervision, detailed presentation of the topic and the results achieved, as well as discussion of their relevance in the context of current research in the written master's thesis, presentation, and defense.

5 Learning outcomes / competencies:

Students

- are able to independently familiarize themselves with a research area,
- are able to independently research international specialist literature on a given topic and gain an overview of the current state of research,
- have the ability to familiarize themselves with a complex measurement method or a complex theoretical concept, and can work on their own research project according to scientific methods and standards.
- can integrate into a research team,
- can write a scientific paper independently,
- can appropriately structure a scientific presentation on their own findings and present it to an audience in the context of the current state of research,
- have learned to deal with critical questions in scientific discussions and to represent their own point of view,
- are familiar with the rules of good scientific practice and apply them,
- are able to draw up a realistic schedule for a large-scale project of their own,
- possess qualifications such as independence and teamwork skills, have a command of German or English technical language in free speech.

6	**Examination:** [] Module final exam (MAP) [] Module exam (MP) [x] Module partial examinations (MTP)

zu	Examination format	Duration or scope	Weighting for the module grade
a)	Master's thesis	60–80 pages	5/6
b)	Oral defense including examination interview	45–60 min	1/6

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** The prerequisite for participation in the oral defense is a passing grade on the written master's thesis.
9	**Requirements for the awarding of credit points:** Credit points are awarded once the master's thesis and the oral defense, including the examination interview, have been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** None
12	**Module coordinator:** Prof. Dr. Cedrik Meier, Prof. Dr. Arno Schindlmayr
13	**Other information:** None