Examination Regulations for the Master's Degree Program in Physics in the Faculty of Science at Paderborn University

of June 16, 2017

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.

On the basis of Section 2 para. 4 and of Section 64 para. 1 of the Higher Education Act of the Region of Nordrhein-Westfalen (Gesetz über die Hochschulen des Landes Nordrhein-Westfalen (Hochschulgesetz – HG)) of September 16, 2014 (GV. NRW. p. 547), Paderborn University has issued the following Examination Regulations:

Contents

I. General

Section 1
Objective and structure of the program, language

(1) The master's examination represents a second degree and professional qualification in the study of physics. In addition to the general learning objectives of Section 58 paragraph 1 HG, the program of study in particular teaches students advanced mathematical and scientific knowledge, an overview of connections between different areas of physics as well as expertise in a particular field of specialization that ties in with current international research, so that they can analyze, formulate and to a large extent solve complex physical problems and questions on a scientific basis. Further, students acquire the skills to familiarize themselves with a new field of specialization, to research the current international scientific literature pertaining to this field, and to independently design, conduct and interpret experiments or, alternatively, to independently develop models and simulations based on theoretical principles in order to solve specific problems. Complementing these technical abilities, students also acquire social skills, an awareness of responsibility as a scientist and of the rules of good scientific practice as well as the ability to discuss complex issues and their own research results in the context of current research, and to convey these orally and in writing.

(2) The program consists of a one-year subject specialization phase, in which the students attend advanced courses in experimental and theoretical physics and choose their own specialization by means of elective courses, followed by a one-year research phase, which centers on the master's thesis and introduces students to independent research work in the field of physics.

(3) The master's examination is intended to determine whether the students have mastered the principles of physics in terms of content and have acquired the systematic overview and methodological tools required for independent research work in the field of physics and its technological applications.

(4) Modules are offered in German and English in the master's program. If the master's program is completed entirely in German or in English, there may be restrictions on choice of electives. Oral and written assessments, including the master's thesis, may be completed in German or English.

Section 2
Academic degree

If the master's examination is passed, the Faculty of Science shall award the academic degree of Master of Science (M.Sc.).

Section 3
Commencement of the program

The program commences in the winter or summer semester.

Section 4
Admission requirements

(1) Applicants may be enrolled in the master's program in physics only if they have acquired the following:

1. A certificate of university entrance (general or specific to a relevant subject) or, in accordance with a legal ordinance, a certificate of entrance to a university of applied sciences, or a

certificate of previous educational qualification recognized as equivalent by legal regulation or by the relevant state authority, or satisfaction of the requirements for qualification through professional training or the requirements of the regulations for admission for applicants from abroad (Bildungsausländerhochschulzugangsverordnung)

2. A degree qualification that meets the following requirements:

   a) It must be an initial university degree with professional qualification with a normal study period of at least six semesters from Paderborn University or a state or state-recognized university or a state or state-recognized university of cooperative education. Degree qualifications from a foreign state or state-recognized university allow admission provided that the competence acquired does not differ significantly from a degree from Paderborn University as per clause 1. For foreign educational qualifications, the equivalence agreements of the Conference of Education Ministers and the Conference of University Rectors or corresponding statutory regulations shall be observed. Insofar as agreements and conventions of the Federal Republic of Germany with other states about equivalence in the university sector (equivalence agreements) work to the advantage of students of foreign countries notwithstanding clause 2, the regulations of the equivalence agreement shall take precedence. In the event of doubt about the existence or absence of significant differences, the Central Agency for Foreign Education (Zentralstelle für ausländisches Bildungswesen) shall also be consulted. The Examinations Board shall determine compliance with the requirements of clause 2.

   b) The degree qualification must include the following competences, as taught on the bachelor's degree program in physics at Paderborn University, or there must be no significant differences from them:

      aa) Experimental physics: Command of the fundamental concepts of classical physics (mechanics, electrodynamics, optics, thermodynamics) and of quantum, atomic, and solid-state physics.

      bb) Theoretical physics: Command of the theoretical principles and methods of classical mechanics, electrodynamics, quantum mechanics and thermodynamics, combined with the ability to create models and abstract mathematical formulation of physical phenomena.

      cc) Physics practicals: Identifying and extracting significant physical interrelationships using experiments conducted by the applicant herself or himself, recording and critically evaluating the results of experiments.

      dd) Mathematics: Command of the fundamental mathematical concepts and methods that are required to understand and solve problems in the master's degree program in physics. This comprises advanced knowledge in the fields of linear algebra, analysis, differential equations, and vector analysis.

      The Examinations Board shall determine compliance with these requirements. If requirements are missing, enrollment may take place on the condition that the requirements are made up by appropriate study and passing of associated examinations before registration for the modules of the research phase. The Examinations Board shall decide on the type and extent of the study and examinations on the basis of the previous degree qualification. Assessments successfully completed outside the degree qualification may also be considered. The missing study which must be made up must not exceed 30 credit points. The study and examinations should be completed in the first semester of the master's degree program.

   c) The degree program must have been completed with an overall grade of at least 3.0 (or an equivalent final grade from abroad).

3. For an applicant who did not acquire his or her admission qualifications at a German-speaking institution, adequate knowledge of the German language. Evidence of linguistic capacity to study is required for unrestricted admission or enrollment for all programs. More detailed information is provided in the Regulations for the German Language Examination for Admission to Paderborn University in their current version.

   Alternatively, an adequate command of the English language shall be demonstrated as follows:

   a. A bachelor’s degree from an English-speaking country or on an English-language accredited domestic program or
   b. Test of English as a Foreign Language (TOEFL) “internet-based” Test (iBT) with a result of at least 80 points or
   c. TOEFL “paper-based” test (PBT) with a result of at least 550 points or
   d. IELTS test with a result of at least 6.0 or
   e. Cambridge English Certificate: Advanced (CAE) or Cambridge English: Proficiency (CPE) or
   f. tests of an equivalent level or
   g. appropriate previous qualification from school.

(2) Enrollment shall be declined if

1. the admission requirements specified in paragraphs 1 and 2 have not been met,
2. the candidate definitively failed to pass an examination required under the Examination Regulations in the relevant program at a university within the scope of the Basic Law or
3. the candidate definitively failed to pass any other examination required under the Examination Regulations in a program at a university within the scope of the Basic Law if both the failed program is close in content to the master’s degree program in physics at Paderborn University and the examination that has been definitively failed has significant proximity in terms of content to an examination in a compulsory module in the master’s degree program in physics at Paderborn University.

Section 5

Normal study period, scope of study, registration for assessments

(1) The normal study period for the master’s degree program in physics is four semesters (including completion of the examinations). This corresponds to a total workload of 3,600 hours (= 120 credit points) for the students.

(2) The master’s program comprises modules with a total of 120 credit points. One credit point, hereafter referred to as CP, corresponds to one ECTS point in accordance with the European Credit Transfer System. One CP corresponds to an average workload of 30 hours. A semester usually comprises 30 CP and thus a workload of 900 hours.

(3) For every assessment that accompanies a course in the subject specialization phase, separate registration is required via the Campus Management System of Paderborn University. Registration is possible only if the admission requirements have been met. Registration shall be completed within the published periods on the Campus Management System of Paderborn University.

(4) Each course is weighted according to the expected workload required in a cumulative credit point system used to indicate completion of assessments. The average workload is set at 1,800 working hours per year of study or an average of 900 working hours per semester and is converted to 60 credit points per year of study or an average of 30 credit points per semester.

Section 6
Modules

(1) The program is modularized. Modules may comprise multiple courses that are linked thematically. The modules are worth 4 to 15 CP (apart from the master's thesis module) and are designed in such a way that they can usually be completed in one to two semesters.

(2) The program comprises compulsory and elective modules in the first year of study with a total of 60 credit points. 18 credit points are allocated to compulsory modules. The elective modules can be selected from a module catalog for the module group concerned. The first half of the second year of study comprises two modules devoted to theoretical and methodological preparation for the master's thesis worth 15 credit points each. The second half of the second year of study is intended for the completion of the master's thesis.

(3) The content of the program shall be selected and restricted in such a way that it can be completed within the normal study period.

Section 7
Recognition of academic work

(1) Academic work on other programs or on programs at other state or state-recognized universities, at state or state-recognized universities of cooperative education, or on programs at foreign state or state-recognized universities shall be recognized if there is no significant difference in the competences acquired from the academic work that is being replaced. This process does not involve a schematic comparison, but an overall consideration of the purpose of recognition for the continuation of study and completion of examinations. Clauses 1 and 2 apply accordingly to the recognition of academic work completed on state-recognized distance programs or in distance study units developed by the region of Nordrhein-Westfalen in conjunction with the other regions and the Federal Republic as a whole.

(2) The equivalence agreements approved by the Conference of Education Ministers and the Conference of University Rectors and agreements in the context of university partnerships shall be observed in recognizing academic work from foreign universities. Insofar as agreements and conventions of the Federal Republic of Germany with other states about equivalence in the university sector (equivalence agreements) work to the advantage of students of foreign countries notwithstanding paragraph 1, the regulations of the equivalence agreement shall take precedence. In the event of doubt about the existence or absence of significant differences, the Central Agency for Foreign Education (Zentralstelle für ausländisches Bildungswesen) may also be consulted.

(3) On request, the Examinations Board must assign the student to a semester on the basis of recognition in accordance with paragraph 1.

(4) Applicants who are entitled to start a program on the basis of a classification examination in accordance with Section 49 para. 12 HG shall have the knowledge and skills they demonstrate in the classification examination recognized as completed academic work. The assessments on the certificate for the classification examination are binding for the Examinations Board.

(5) On application, other knowledge and qualifications based on submitted documentation may be recognized by the Examinations Board if that knowledge and those qualifications are equivalent in content and level to the academic work that they are intended to replace.

(6) The Examinations Board is responsible for recognition in accordance with paragraphs 1 and 5. Before determining the existence or absence of significant differences or equivalence, relevant subject representatives shall be consulted. If recognition is refused, the reasons for the decision must be given.

(7) The applicant shall provide the information required (in particular, the knowledge and skills acquired through the academic work and the examination results) for recognition in the form specified by the Examinations Board. The Examinations Board shall decide on applications under paragraph 1 at the latest within ten weeks of full submission of all information required for the decision.

(8) Recognition shall be indicated on the certificate. If academic work is recognized, the grades shall be transferred following conversion as necessary, insofar as the assessment systems are comparable, and included in the respective grade calculation. If no grade is available or if the assessment systems are not comparable, the comment “passed” shall be entered.

(9) A piece of academic work can only be recognized once. This also applies to recognition of other knowledge and qualifications.

Section 8
Examinations Board

(1) For the organization of examinations at Paderborn University and of the tasks assigned by these Examination Regulations, the Faculty Board shall, at the request of the Department of Physics, constitute an Examinations Board to

1. organize examinations and monitor the way in which they are conducted,
2. ensure compliance with the Examination Regulations and adherence to the procedural regulations agreed for conducting the examinations,
3. decide on inconsistencies in decisions taken in examination procedures,
4. draft an annual report to the Faculty Board, the Dean of Studies and the Departmental Board on developments in examinations and study periods,
5. carry out any other tasks expressly assigned to the Examinations Board by these Regulations.

In addition, the Examinations Board shall make suggestions for reform of the Examination Regulations and shall publish the distribution of grades. The Chair of the Examinations Board is assigned specific tasks by these Regulations. The Examinations Board may assign completion of matters that have no fundamental importance to the Chair; this does not apply to decisions about inconsistencies or to the annual report. The Chair shall report to the Examinations Board on decisions made by her or him alone. The Examinations Board and the Chair of the Examinations Board shall be supported by the Central Examinations Office.

(2) The Examinations Board consists of the Chair, the Deputy Chair, and one further member from the group of lecturing staff, a member from the group of academic assistants, and a student member. Both the Chair and the Deputy Chair must belong to the group of university lecturing staff. The members of the Examinations Board are elected by their respective representatives on the Faculty Board according to their groups. With the exception of the Chair and the Deputy Chair, deputies for the members of the Examinations Board shall be elected accordingly. The period in office of the members from the group of university lecturing staff and from the group of academic assistants is three years; the period in office of the student members is one year. Re-election is permitted. The regulations regarding gender equality pursuant to Section 11c HG must be observed in the composition of the Board.

(3) The Examinations Board is an authority as defined by administrative procedural and administrative process law.

(4) The Examinations Board has a quorum if, in addition to the Chair or the Deputy Chair and one further member of lecturing staff, at least one other member with voting rights is present. The Examinations Board shall make decisions by simple majority. In the event of an equal number of votes being cast, the Chair shall have the casting vote. The student member of the Examinations

Board shall act only in an advisory capacity in pedagogical-academic decisions, in particular in the evaluation and recognition of academic work.

(5) The Examinations Board is convened by the Chair. The Examinations Board must be convened if at least three of its members so demand.

(6) The meetings of the Examinations Board are not public. The members of the Examinations Board, their deputies, the examiners, and the observers are *ex officio* obliged to maintain confidentiality. If they are not civil servants, they shall be obliged to maintain confidentiality by the Chair of the Examinations Board.

(7) The members of the Examinations Board have the right to attend the examinations when they are being taken.

Section 9
Examiners and observers

(1) The Chair of the Examinations Board shall appoint the examiners and observers. The examiners are usually all independent teachers of the courses in which examinations may be taken in accordance with the specifications of the curriculum and the module descriptions. The group of examiners may be extended within the framework of the Higher Education Act. Only those who have at least passed the relevant master's examination or a comparable examination may be appointed as observers.

(2) Examiners are independent in their examination work.

(3) The candidate may propose examiners for the modules in the research phase and – if several examiners are available to choose from – for the oral examinations in the subject specialization phase. The candidate's proposals shall be accommodated as far as possible. There is no legal entitlement.

(4) The Chair of the Examinations Board shall ensure that the candidate is notified of the names of the examiners in good time, usually four, but at least two weeks before the date of the corresponding examination. Announcement on the Campus Management System of Paderborn University is sufficient.

Section 10
Failure to appear, withdrawal, unfair practice, breach of regulations, protection provisions

(1) An assessment is deemed to be "non-sufficient/fail" (5.0) if

- the candidate fails to appear at an examination without good reason or
- leaves after the start of the examination without good reason or
- withdraws from the examination after the registration periods specified under paragraph 2 have elapsed without giving good reasons or
- a written assessment is not completed within the specified time.

(2) The candidate may withdraw from an examination for which she or he has registered on the Campus Management System of Paderborn University without specifying reasons up to a week before the examination date set via the Campus Management System. In the case of practicals, the candidate may withdraw from an examination without specifying reasons up to a week before the first experiment via the Campus Management System.

(3) After the period specified under paragraph 2, the reasons asserted for the failure to appear at or withdrawal from the examination must be made known immediately by the candidate to the Examinations Board to its satisfaction, and at the latest five working days from the respective

examination date. In the event of illness of the candidate, a medical certificate dated on the day of the examination at the latest confirming incapacity to take the examination is sufficient. If there is sufficient factual evidence to suggest that incapacity to complete the examination is likely or other evidence that appears to be relevant, a medical certificate from a medical officer of Paderborn University may be demanded at the cost of the University. The medically certified illness of a child, as defined under Section 25 para. 5 of the German Federal Education and Training Assistance Act (BAföG), constitutes incapacity of the candidate to take the examination if alternative arrangements for childcare cannot be made, in particular if parental care is provided mainly by the candidate alone. If the Examinations Board accepts the reasons, the candidate shall be notified in writing and a new examination date shall be set. If the Examinations Board does not accept the reasons, the candidate shall be notified in writing. The examination results already available shall count if the reasons are accepted.

(4) If a candidate engages in unfair practice or attempts to engage in unfair practice, the examination concerned is deemed to have been given the grade “non-sufficient/fail” (5.0). If a candidate uses an unauthorized aid, the assessment concerned may be given the grade “non-sufficient/fail” (5.0). The incidents shall be recorded by the supervisors concerned. The determination pursuant to clause 1 or the decision pursuant to clause 2 shall be made by the respective examiner.

(5) A candidate who disrupts the orderly course of the examination may be excluded from continuing to sit the examination, usually following a warning, by the respective examiners or supervisors; in this case, the assessment is deemed to have been given the grade “non-sufficient/fail” (5.0). The reasons for the exclusion shall be recorded.

(6) The candidate may demand within 14 days that decisions under paragraph 4 or paragraph 5 be reviewed by the Examinations Board. The candidate shall be notified of negative decisions immediately in writing by the Examinations Board and provided with the reasons and with information about legal remedies. Before the decision is made, the candidate shall be given the right to be heard.

(7) In serious cases, the Examinations Board may exclude the candidate from taking further assessments. Unfair practice may also incur a financial penalty of up to €50,000 in accordance with Section 63 para. 5 HG and lead to exmatriculation (removal from the register of students).

(8) The Examinations Board shall also decide on compensation for disadvantages for students with a disability or chronic illness. If, as a result of their disability or chronic illness, students are not in a position to complete assessments in whole or in part using the intended methods, compensation for the disadvantage shall be granted. Compensation for disadvantage to be considered includes taking organizational measures or providing organizational aids, extending deadlines, or offering a different, equivalent form of assessment. Evidence of disability or chronic illness must be provided. A medical report or psychological assessment may be required for this purpose. The application shall specify and justify the modifications requested. At the request of the student or of the Examinations Board in agreement with the student, the Officer for Students with Disabilities or Chronic Illnesses may provide recommendations for the form of compensation for disadvantage.

(9) Account shall be given to the particular situation of students with family obligations when studying and completing assessments. This can be done in the following ways, among others:

a) At the request of a candidate, the protective provisions pursuant to Sections 3, 4, 6 and 8 of the German Maternity Protection Act (MSchG) shall be observed as appropriate. The necessary evidence shall be attached to the application. The Examinations Board may decide on alternative forms of assessment, taking the individual case into account. The maternity protection periods shall interrupt all periods specified by these Examination Regulations; the duration of the maternity protection shall not be included in the period concerned.

b) Similarly, the periods of parental leave in accordance with the applicable German Federal Parental Benefit and Parental Leave Act (BEEFG) shall be observed on request. The candidate shall notify the Examinations Board in writing, attaching the necessary evidence, of the period or periods for which she or he wishes to take parental leave at the latest four weeks before the time from which she or he wishes to take parental leave. The Examinations Board shall check that the statutory requirements which would trigger a right to parental leave for an employee under the Federal Parental Benefit and Parental Leave Act have been met and shall set the deadlines and periods in accordance with the individual case. The submission period for the master's thesis may be extended to a maximum of twice the intended completion period. Otherwise, the thesis is deemed not to have been assigned and the candidate shall be given a new topic upon expiry of the parental leave.

c) On request, the Examinations Board shall take account of absences resulting from the care and upbringing of children as defined by Section 25 para. 5 of the Federal Education and Training Support Act and absences for the care of a spouse, registered civil partner, or partner in a cohabitation relationship, or of an immediate relative or immediate in-law, and shall set periods and deadlines in accordance with the individual case. Clauses 4 and 5 of letter b) also apply accordingly.

II. Master's examination

Section 11
Type and scope of the master's examination

(1) The master's examination consists of the following module examinations associated with the program of study:
   a. Two elective modules from the module group *Experimental Physics* with 6 credit points each
   b. Compulsory module *Quantum Mechanics II* with 8 credit points
   c. Two elective modules from the module group *Theoretical Physics* with 6 credit points each
   d. Three elective modules from the module group *Specialization* with 6 credit points each
   e. Compulsory module *Main Seminar* with 4 credit points
   f. Compulsory module *Technical English II* with 6 credit points
   g. Compulsory modules *Preparation for the Master's Thesis: Theory* and *Preparation for the Master's Thesis: Methods* with 15 credit points each
   h. The *Master's Thesis* module with 30 credit points.

(2) The module descriptions for the compulsory and elective modules are attached to the Examination Regulations in the Appendix.

Section 12
Admission to examinations

(1) Only those who are enrolled for the master's degree in physics at Paderborn University or are registered as visiting students in accordance with Section 52 HG may be admitted to examinations for the master's degree in physics. These requirements must also be observed during the examinations.

(2) In accordance with available capacity and on application to the Examinations Board, in addition to paragraph 1 students on the bachelor's degree program in physics who have acquired at least 152 credit points relevant to their graduation and who are likely to meet the admission requirements for the master's degree program may be admitted to modules on the master's degree program worth a maximum of 30 credit points for one semester. Use may be made of this regulation once only. Repetition of a failed master's examination taken in advance is only possible after enrollment in the

master’s degree program. Students do not have a right to be admitted to the master’s degree program in physics at a later date.

(3) Only those who have successfully completed the module *Quantum Mechanics II*, have achieved at least 48 CP and, in the case of conditional enrollment pursuant to Section 4, have passed the relevant examinations may be admitted to the research phase.

(4) Only those who have successfully completed the modules “Preparation for the master’s thesis: Theory” and “Preparation for the master’s thesis: Methods” in the research phase may be admitted to the master’s thesis.

(5) Registration for the research phase shall be submitted in writing to the Chair of the Examinations Board via the Central Examinations Office. Evidence of compliance with the admission requirements specified in paragraphs 1 and 3 shall be appended to the registration.

(6) Registration for admission to the master’s thesis shall be submitted in writing to the Chair of the Examinations Board via the Central Examinations Office. Evidence of compliance with the admission requirements specified in paragraphs 1 and 4 shall be appended to the registration.

(7) Admission to the master’s thesis shall be refused if the requirements specified in paragraphs 4 and 6 are not met.

(8) Further requirements for participation in examinations may be stipulated in the module descriptions.

Section 13
Completion of a module

(1) Every module in the master’s program is concluded with a module examination. This module examination shall take place in temporal proximity to the module. A module examination usually takes the form of an examination at the end of the module (final module examination). However, the module examination can also take place in the course of the module (in particular, in temporal proximity to a course) or consist of several partial examinations (partial module examinations). If the module examination consists of several partial module examinations, each partial module examination must be passed. The module grade corresponds to the grade achieved in the module examination.

(2) Credit points may be acquired only if the module has been completed in full. A module is completed successfully when the final module examination or partial module examinations have been passed with a minimum grade of “sufficient.”

Section 14
Forms of assessment in the modules and certified participation

(1) Assessments may take the form of written examinations, oral examinations, written homework with subsequent presentation, or other forms. The precise allocation of individual assessments is indicated in the module descriptions in the Appendix. With the exception of oral examinations, students shall usually be notified of their grade on the Campus Management System of Paderborn University at the latest six weeks after the assessment has been completed.

(2) A distinction is made between the following types of assessment:

a) Written examinations

In written examinations, the candidate is expected to demonstrate that she or he is able to identify problems in the subject area in a specified time using resources permitted by the examiner and to solve them using standard methods.

Written examinations are usually graded by one examiner. A final attempt at an examination shall be graded by two examiners.

The duration of a written examination is indicated in the module descriptions. Written examinations using the multiple-choice system are not permitted. The examiner shall determine which resources may be used in written examinations. A list of approved resources shall be announced with the date of the examination.

b) Oral examinations

In the oral examinations, the candidate is expected to demonstrate that she or he can recognize the interrelationships within the examination area and can classify specific questions in this context. Oral examinations are also intended to establish whether the candidate has a broad basic knowledge.

Oral examinations shall be held in front of at least two examiners (examination before a panel) or in front of one examiner in the presence of a knowledgeable observer, as group or individual examinations. Simultaneous examination of up to four candidates is permitted. Before determining the grade, the examiner shall listen to the views of the other examiners on the panel or the observer without the candidate being present. A final attempt at an examination shall be graded by two examiners.

The duration of oral examinations is indicated in the module descriptions. In the case of group examinations, the overall duration of the examination shall be extended accordingly.

The key points and results of the examination shall be recorded in a report. The candidate shall be notified of the result by the examiner following the oral examination.

Students who want to take the same examination at a later examination date shall be admitted to listen to the examination if space permits and provided that there is no objection from a candidate. Admission does not include advice or notification of the result of the examination to the candidate.

c) Written report followed by a presentation

Written reports are written analyses of a topic developed independently in the thematic area of a course. The topic of a written report is described in an oral presentation with subsequent discussion. The length of the written report and the duration of the presentation are indicated in the module descriptions.

d) Oral presentation

Oral presentations of a topic are developed independently in the thematic area of a course. In the process, students are expected to demonstrate that they are capable of research into and scientific analysis of a specific topic and that they can convey the results. The topic shall be agreed with the teacher. The length is specified in the module descriptions.

d) Assessment of practicals

In the case of practicals, assessment comprises a specified number of experiments from a catalog of experiments organized according to content. An experiment comprises preparation (including research of the literature), execution (including reflections on comments of the supervisor), written analysis (in particular the practical report, including research of the literature), presentation, and discussion of the written analysis. One grade is given to all of the written analyses (including the presentations and discussions) of the experiments.

In the practicals, candidates are expected to demonstrate that they can prepare an experimental task appropriately, conduct it while taking safety aspects into account, evaluate, and document it. In order to practice collaboration and in the interests of safety, experiments are usually conducted in small groups of two to four students. Participation in practical meetings is compulsory.

Before each experiment begins, the supervisor shall verify that the students' preparation is adequate to conduct the experiment successfully and safely. If this is not the case, the experiment can only be carried out at a later date.

While the experiment is being conducted, an original measurement report is recorded and signed off by the supervisor.

A new experiment usually cannot be started until the analysis of the previous experiment has been submitted.

Deficiencies in the analysis and presentation can be improved within a further week.

(3) Certified participation is confirmed when the work completed indicates that there has been more than superficial engagement with the subjects underlying a task.

Section 15
Assessments in the modules

(1) Assessments are completed in the master's degree program in physics in accordance with the specifications of the module descriptions. The grades from the module examinations go towards the final grade for the master's examination. They are weighted according to the credit points achieved.

(2) If the module descriptions include overall guidelines as to the form and/or duration/extent of assessments, the Examinations Board shall define in consultation with the examiner how, specifically, the assessment is to be completed. In all courses, confirmation of how the assessment is to be completed shall be given at the latest in the third week from the start of teaching by the teacher concerned. This applies accordingly to evidence of certified participation. Assessments are related to the content and skills acquired in the associated courses.

(3) Students who are more than one semester behind in completing their subject examinations for a section of the program are strongly recommended to attend an advisory meeting.

Section 16
Grading of assessments in the modules

(1) The grades for the individual assessments are determined by the respective examiners. The following grades shall be used for assessment:

1= very good = an outstanding performance;
2 = good = a performance significantly above the average requirements;
3 = satisfactory = a performance that meets the average requirements;
4 = sufficient = a performance which, despite its defects, still satisfies the requirements;
5 = non-sufficient/fail = a performance which no longer satisfies the requirements because of serious defects.

(2) For more differentiated grading, intermediate grades can be created by raising or lowering the individual grade by 0.3. The intermediate grades 0.7, 4.3, 4.7, and 5.3 are not permitted.

(3) If a module grade is made up of several grades together, the arithmetic mean shall be taken, weighted according to the workload of the associated course. The result shall be accurate to one decimal place. The grades are:

for an average up to 1.5 = very good
for an average of 1.6 to 2.5 = good
for an average of 2.6 to 3.5 = satisfactory

for an average of 3.6 to 4.0 = sufficient

for an average over 4.0 = non-sufficient/fail.

(4) If an examination is graded by several examiners and the results vary, the grade shall be determined by the arithmetic mean of the grades of all examiners. Otherwise, paragraph 3 applies accordingly.

(5) Evidence of certified participation must be provided.

Section 17
Research phase

The research phase serves to acquire research-related skills on the basis of a specific research project. The student is expected to show that she or her is able to work independently on a research task from the subject area of physics and to describe the task, the method used for solving it, and the solution comprehensibly and to interpret it appropriately. The research phase is an integral part of scientific training. It accounts for a total of 60 credit points and is divided into three modules:

- A theoretical preparation module (15 CP): In this module, the specialist knowledge required for the project is acquired by means of independent study of the literature and/or attending appropriate courses.
- A methodological preparation module (15 CP): This module is used to acquire experimental-practical or theoretical-mathematical skills, which are required to deal with the research topic.
- Completion of the master's thesis and oral defense with subsequent assessed discussion (30 CP together): This module comprises completion of the project and written documentation and public presentation of it.

Section 18
Master's thesis

(1) The master's thesis is an assessment with which the master's degree program is completed. It represents the third part of the research phase and takes place immediately after the two preparation modules of the research phase.

(2) The topic for the master's thesis may be assigned and supervised by professors, junior professors, private and university tutors, academic assistants with Habilitation, assistants with Habilitation, and heads of junior research groups, provided that they are involved in research and teaching in the subject area of Physics at Paderborn University. The master's thesis may also be completed outside Paderborn University if the topic is assigned and supervised by an individual from the group of persons listed in clause 1. University lecturers or examiners authorized in accordance with Section 65 paragraph 1 HG with Habilitation who are involved in research and teaching at Paderborn University outside the subject area of Physics may also assign and supervise topics for the master's thesis. The person who assigns the topic and the supervisor shall be appointed by the Chair of the Examinations Board.

(3) The candidate has the right to propose the person who assigns the topic and the topic itself. This does not justify any legal claim.

(4) The candidate shall attempt to arrange a topic for the master's thesis herself or himself. On application, the Chair of the Examinations Board shall ensure that the candidate is given a topic for the master's thesis in good time. The time at which the topic is issued shall be recorded by the Central Examinations Office.

(5) The completion time for the master's thesis is five months. Topic, question, and scope of the master's thesis shall be circumscribed in such a way that it can be completed within the framework

of the intended workload of approx. 750 hours. In individual cases, the Examinations Board may exceptionally extend the completion period by up to eight weeks on justified application by the candidate, if the reasons relate to the topic of the thesis and the supervisor pursuant to paragraph 2 agrees.

(6) If the candidate falls ill during the completion period, she or he may apply for an extension to the submission deadline for the master's thesis of a maximum of four weeks. Immediate submission of a medical certificate is essential in this case. A medical certificate confirming incapacity to take the examination is sufficient. If there is sufficient factual evidence to suggest that incapacity to complete the examination is likely or other evidence that appears to be relevant, a medical certificate from a medical officer of Paderborn University may be demanded at the cost of the University. If the Examinations Board accepts the application, the candidate shall be notified in writing. The extension shall correspond to the period of illness; it does not entail an extension of the normal study period. If the period of the illness exceeds four weeks, the candidate may, at her or his discretion, complete the thesis within the deadline extended by four weeks or apply for a new topic. If the Examinations Board rejects the application, the candidate shall likewise be notified in writing.

(7) The topic for the master's thesis may be returned only once and within the first four weeks from assignment.

(8) On submission of the master's thesis, the candidate shall confirm in writing that she or he has written the thesis herself or himself and has cited or specified the sources and resources used. The length of the master's thesis shall be appropriate to the subject covered, with the aim of maximum concision. The length of the thesis shall be between 40 and 80 pages.

(9) The master's thesis, including extracts thereof, must not have been prepared for another examination on the same program or any other program.

Section 19
Submission and grading of the master's thesis

(1) Two copies of the master's thesis shall be submitted on time to the Central Examinations Office; the time of submission shall be recorded. If the thesis is submitted by post, the time of submission to the post office (postmark) is definitive. If the master's thesis is not submitted on time, it shall be graded “non-sufficient/fail” (5.0).

(2) The master's thesis shall be assessed and graded by two examiners. At least one of them shall be a teacher of physics. Only one of the examiners may be a junior research group leader. One of the examiners shall be the supervisor, while the second examiner shall be appointed by the Chair of the Examinations Board from the group of persons specified in Section 18 paragraph 2 clauses 1 and 3.

The individual grading shall be carried out in accordance with Section 16 and shall be justified in writing. The grade for the thesis shall be determined by the arithmetic mean of the individual grades in accordance with Section 16, provided that the difference is not greater than 2.0 and the individual grades are a minimum of “sufficient.” If the difference is greater than 2.0 or one of the grades is “non-sufficient/fail” while the other is “sufficient” or better, a third examiner shall be appointed by the Chair of the Examinations Board to assess the master's thesis. In this case, the grade for the thesis shall be determined by the arithmetic mean of the three grades. However, the thesis may only be assessed as “sufficient” or better if at least two of the grades are “sufficient” or better. Otherwise, the master's thesis is deemed to have been failed.

(3) The student shall be notified of the grade for the master's thesis at the latest four weeks after submission on the Campus Management System of Paderborn University.

Section 20
Oral defense of the master's thesis

(1) At the latest six weeks after submission of the dissertation, an oral defense of the master's thesis shall be held, followed by an assessed discussion of the topic of the written master's thesis and its results (referred to together in subsequent paragraphs of the Regulations as "oral defense"). The oral defense, including the assessed discussion, shall last a minimum of 45 minutes and a maximum of 60 minutes.

(2) During the oral defense of the master's thesis, the candidate shall briefly present and explain its main themes and findings. In the following assessed discussion, the candidate is expected to demonstrate a fundamental understanding of relevant interrelationships in physics in direct relation to the completed thesis and in the narrow context of the completed thesis' content.

(3) The oral defense of the master's thesis, including the assessed discussion, shall take place in front of two examiners, who are usually identical with the assessors of the master's thesis pursuant to Section 19 para. 2. If the grades deviate from one another, the grade shall be determined by the arithmetic mean of the two individual grades. The oral defense and assessed discussion shall be graded together.

(4) The key points and results of the oral defense, including the assessed discussion, shall be recorded in a report. The candidate shall be notified of the result by the examiners following the oral defense.

Section 21
Additional modules

In addition to the courses required for the degree program, students may complete further modules beyond those required for the master's examination (additional modules). The module grades achieved in additional modules shall be listed on the Transcript of Records unless the student requests otherwise. They shall not be taken into account in determining the overall grade for the master's examination. The additional modules shall be marked as such on enrollment.

Section 22
Retaking assessments

(1) A final module examination or partial module examination that has been passed can neither be retaken nor improved.

(2) An examination for a compulsory or elective module that has been failed in the subject specialization phase can be retaken three times.

(3) A module is definitively failed if the final module examination or a partial module examination cannot be retaken again.

(4) On registration for an examination in an elective module in the subject specialization phase, that module is deemed to have been chosen. Substitution of elective modules is possible, including those that have been failed definitively. An application must be made in writing to the Central Examinations Office. The number of substitution options is restricted to the number of modules available for selection in each elective area. Modules that have already been passed may not be substituted.

(5) A preparation module in the research phase may be repeated twice if it is graded "non-sufficient/ fail." The total number of opportunities to retake preparation modules is limited to two.

(6) The master's thesis may be retaken once if it is graded "non-sufficient/fail." A new topic must be set in this case. In the case of a retake of the master's thesis, a return of the topic within the period

specified in Section 18 paragraph 7 is only permitted, however, if the option to return the topic was not exercised in the first attempt.

(7) The master's thesis and its oral defense shall normally be retaken in the next semester.

(8) The oral defense may be retaken once if it is graded "non-sufficient/fail." In this case, the Examinations Board shall set a date for the retake in consultation with the candidate. This shall be in the course of the following eight weeks. The Examinations Board shall decide on legitimate exceptions.

(9) If the oral defense of the master's thesis is failed definitively, the master's thesis is also deemed to have been failed. In this case, Section 6 applies.

Section 23
Assessment of the master's examination and determination of overall grade

(1) The master's thesis has been passed when all module examinations, the master's thesis, and the oral defense have received a minimum grade of "sufficient" (4.0). The requirements for successful completion of the program are specified in Section 24.

(2) The overall grade is determined by weighting the module grades and the grade for the master's thesis according to credit points and calculating the arithmetic mean. In calculating the result, only the first decimal place shall be taken into consideration; all other decimal places shall be deleted without rounding. The grades are:

for an average up to and including 1.5	= very good
for an average over 1.5 up to and including 2.5	= good
for an average over 2.5 up to and including 3.5	= satisfactory
for an average over 3.5 up to and including 4.0	= sufficient
for an average over 4.0 up to 5.0	= non-sufficient/fail.

(3) The overall grade "very good" shall be replaced with "passed with distinction" if the overall grade for the master's thesis is 1.0 and the weighted average corresponding to paragraph 2 for the remaining assessments is 1.3 or better.

Section 24
Successful completion of the program, definitive failure

(1) The program has been successfully completed when the master's examination has been passed and all modules have been completed successfully. The master's examination has been passed when all module examinations, the master's thesis, and the oral defense have received a minimum grade of "sufficient" (4.0).

(2) The master's examination has been failed definitively if

1. a module has been failed definitively and it cannot be substituted in accordance with Section 22 paragraph 4 or
2. the master's thesis cannot be retaken.

(3) The decision of a definitive failure of the master's examination shall be communicated to the candidate in written form by the Chair of the Examinations Board. The decision shall be communicated with information about possible legal remedies.

(4) If a candidate has definitively failed the master's examination, on request she or he shall be issued with a transcript which includes the assessments completed and any credit points (CP) awarded, and which indicates that the master's examination has been failed definitively.

(5) On request, students who withdraw from the University for other reasons without graduating shall be issued with a transcript following exmatriculation, which includes the assessments completed and any credit points (CP) awarded.

Section 25
Certificate, Transcript of Records, Diploma Supplement

(1) If the candidate has successfully completed the program, she or he shall receive a certificate confirming the result. This certificate shall include the name of the program, the normal study period, and the overall grade. The certificate shall indicate the date on which the last assessment was completed. It shall also show the date on which it was issued. The certificate shall be signed by the Chair of the Examinations Board.

(2) In addition, the candidate shall receive a Transcript of Records in which all of the assessments completed and the study period are listed. The Transcript of Records includes details of the credit points (CP) and the grades achieved for the completed modules and for the master’s thesis. It also includes the topic of the master’s thesis and the overall grade achieved for the master’s examination.

(3) With the final certificate, the graduate shall also be issued with a Diploma Supplement.

(4) The Diploma Supplement is an addition to the certificate in German and English with standard information about German university degree qualifications; it explains the German education system and the place of the present degree qualification in it. The Diploma Supplement provides information about the completed degree program and the academic and professional qualifications achieved with it. The Diploma Supplement includes the central content of the program on which it is based, the program of study, the skills achieved on graduation, and the awarding university.

Section 26
Master’s Certificate

(1) Along with the certificate for completion of the degree, the candidate shall be provided with a Master’s Certificate with the date of the certificate. This certifies the award of the master’s degree in accordance with Section 2.

(2) The Master’s Certificate shall be signed by the Dean of the Faculty of Science and the Chair of the Examinations Board and provided with the seal of Paderborn University.

(3) An English translation shall be attached to the Master’s Certificate.

Section 27
Access to the examination files

(1) Following release of the grades, the candidate may be given the opportunity to have access to her or his written assessments and the evaluation of the examiners relating to them. The Chair of the Examinations Board shall determine the location and time at which access is provided; she or he may assign these tasks to the examiners. The location and time at which access is provided shall be made known during the examination, at the latest on release of the grade.

(2) If paragraph 1 does not apply, on application within a month of release of the results of the respective examinations the candidate shall be given the opportunity to have access to her or his written assessments and the evaluations of the examiners relating to them and to the examination records. Within one year of issue of the certificate, the candidate shall be given access on request to the master’s thesis, the related evaluations of the examiners, and the examination records within

an appropriate period. The Chair of the Examinations Board shall determine the location and time at which access is provided; she or he may assign these tasks to the examiners.

III. Final provisions

Section 28
Invalidity of the master’s examination

(1) If a candidate has engaged in unfair practice in an examination and if this fact only becomes apparent after the certificate has been issued, the Examinations Board may subsequently adjust the grades accordingly for those examinations in which the candidate engaged in unfair practice and declare the examination failed in whole or in part.

(2) If the requirements for admission to an examination were not met, without the candidate intending to deceive, and if this fact becomes apparent only after the certificate has been issued, this defect shall be remedied by passing the exam. If the candidate has intentionally brought about admission by deceit, the Examinations Board shall decide on the legal consequences, taking account of the Administrative Procedures Act for the region of Nordrhein-Westfalen.

(3) The candidate shall be given the opportunity to speak before any decision is made.

(4) The incorrect examination certificate shall be retracted and, if appropriate, a new one shall be issued. A decision in accordance with paragraph 1 and paragraph 2 clause 2 is excluded after a period of five years from the date of issue of the examination certificate.

(5) If the examination as a whole has been declared to have been failed, the master’s degree shall be withdrawn and the Master’s Certificate retracted. Withdrawal of the master’s degree is permitted only within five years of the date on which the degree was awarded.

Section 29
Withdrawal of the master’s degree

The master’s degree shall be withdrawn if it subsequently transpires that it has been obtained by unfair practice or if significant requirements for the award have mistakenly been considered to have been met. The Faculty Board of the Faculty of Science of Paderborn University shall decide on the withdrawal by a two-thirds majority of its members. Withdrawal of the master’s degree is permitted only within five years of the date on which the degree was awarded.

Section 30
Transitional provisions

(1) These Examination Regulations shall apply to all students who are enrolled for the first time in the master’s degree program in physics at Paderborn University from the winter semester 2017/2018.

(2) Students who were enrolled for the master’s degree program in physics at Paderborn University before the winter semester 2017/2018 may take their master’s examination, including retakes, under the Examination Regulations that apply to them in the summer semester 2017 for the last time in the winter semester 2020/2021. Shorter periods from older transitional provisions remain unaffected.

(3) On application, students on the master’s degree program in physics may change to the Examination Regulations that apply from the winter semester 2017/2018. The change cannot be reversed.

(4) In justified cases, the Examinations Board may pass special transitional provisions on application.

Section 31
Effectiveness and publication

(1) These Examination Regulations shall come into force on October 1, 2017. The Examination Regulations for the master’s degree program in physics in the Faculty of Science at Paderborn University of June 28, 2012 (AM.Uni.Pb. 27.12) shall cease to apply. Section 30 remains unaffected.

(2) These Examination Regulations shall be published in the Official Bulletin of Paderborn University (AM.Uni.Pb.).

Drafted on the basis of the resolution of the Faculty Board of the Faculty of Science of May 17, 2017 and checked for legal compliance by the Executive Board of Paderborn University on May 24, 2017.

Paderborn, June 16, 2017

On behalf of the President
The Vice-President for Operations
of Paderborn University

Simone Probst

Appendix: Curriculum and module descriptions

Curriculum

Semester	Module group	Module	Workload (h)	Total (h)
1. Semester	Experimental Physics	Elective module	180	930
	Quantum Mechanics II	Quantum Mechanics II	240	
	Specialization	Elective module	180	
	Specialization	Elective module	180	
	Advanced Seminar	Advanced Seminar	60	
	English for Technical Purposes II	English Oral Skills	90	
2. Semester	Experimental Physics	Elective module	180	870
	Theoretical Physics	Elective module	180	
	Theoretical Physics	Elective module	180	
	Specialization	Elective module	180	
	Advanced Seminar	Advanced Seminar	60	
	English for Technical Purposes II	Introduction to Academic Writing for MINT Students *or* English for Profession and Study Abroad	90	
3. Semester	Preparation	Theory	450	900
	Preparation	Methods	450	
4. Semester	Master's Thesis	Master's Thesis Oral Defense	750 150	900
				3,600

This curriculum is intended as a recommendation and guidance and can be individually rearranged. The requirements for admission to certain modules as detailed in the module descriptions must be observed in this case.

Module list

Module group Experimental Physics	Contact hours per week and semester	Credit points
Nonlinear Optics	Lect 2; Exerc 2	6
Physics and Technology of Nanomaterials	Lect 2; Exerc 2	6
Quantum Optics	Lect 2; Exerc 2	6
Laboratory Course	Lab 4	6

Module Quantum Mechanics II	Contact hours per week and semester	Credit points
Quantum Mechanics II	Lect 4; Exerc 2	8

Module group Theoretical Physics	Contact hours per week and semester	Credit points
Group Theory	Lect 2; Exerc 2	6
Optics of Solid-State Systems and Nanostructures	Lect 2; Exerc 2	6
Theory of Quantum Information	Lect 2; Exerc 2	6
Relativistic Quantum Field Theory	Lect 2; Exerc 2	6
Theory of Relativity	Lect 2; Exerc 2	6
Theoretical Quantum Optics	Lect 2; Exerc 2	6
Many-Body Theory of Solids	Lect 2; Exerc 2	6

Module group Specialization	Contact hours per week and semester	Credit points
Atomistic Materials Modeling	Lect 2; Exerc 2	6
Computational Optoelectronics and Photonics I	Lect 2; Exerc 2	6
Computational Optoelectronics and Photonics II	Lect 2; Exerc 2	6
Computational Spectroscopy	Lect 2; Exerc 2	6
Semiconductor Epitaxy	Lect 2; Exerc 2	6
Integrated Optics and Photonics	Lect 2; Exerc 2	6
Ion Beam Analysis	Lect 1; Lab 2; Sem 1	6
Microscopy and Spectroscopy with Electrons	Lect 2; Exerc 2	6
Low-Dimensional Semiconductor Systems: Electrical Properties	Lect 2; Exerc 2	6

Low-Dimensional Semiconductor Systems: Optical Properties	Lect 2; Exerc 2	6
Optoelectronic Semiconductor Devices	Lect 2; Exerc 2	6
Photonic Nanostructures	Lect 2; Exerc 2	6
Quantum Electronics	Lect 2; Exerc 2	6
Quantum Communication and Information	Lect 2; Exerc 2	6
Spintronics	Lect 2; Exerc 2	6

Module Advanced Seminar	**Contact hours per week and semester**	**Credit points**
Advanced Seminar	Sem 2	4
Advanced Seminar	Sem 2	

Module English for Technical Purposes II	**Contact hours per week and semester**	**Credit points**
English Oral Skills	Exerc 2	6
Introduction to Academic Writing *or*	Exerc 2	
English for Profession and Study Abroad		

Modules of the Research Phase	**Duration**	**Credit points**
Preparation for the Master's Thesis: Theory	6 months	15
Preparation for the Master's Thesis: Methods		15
Master's Thesis	5 months	30
Oral Defense		

Module descriptions

Nonlinear Optics

Nichtlineare Optik

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Experimental Physics	180	6	2nd	Summer semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Nonlinear Optics	Lect	30	60	Elective	up to 240
b)	Nonlinear Optics	Exerc	30	60	Elective	up to 30

2 Options within the module:

none

3 Requirements for admission:

none

4 Contents:

- Nonlinear optical susceptibility (description of nonlinear optical processes, formal definition and properties of the 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-optical and photorefractive effects (electro-optical effect, electro-optical modulators, photorefractive effect)

5 Learning outcomes / Skills:

The students are expected to be capable of applying the fundamental concepts of nonlinear optics correctly and effectively to typical problems in physics and of solving these on their own.

The students

- can identify and analyze questions in the field of nonlinear optics and recognize the differences with respect to linear optics,
- can apply approximations to solve nonlinear wave equations,
- can independently identify problems in nonlinear optics and develop appropriate strategies to solve standard problems that include nonlinear effects,
- are able to make simple abstractions of more complex problems when dealing with nonlinear optical effects and to transfer these to approximations for solving the problems,
- have the ability to independently assess complex physical relationships in nonlinear optics and to evaluate numerical or analytical approaches to their approximations using the acquired knowledge,
- can deal with current English-language literature on topics of nonlinear optics on their own.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

The module is also used in the master program Optoelectronics and Photonics.

12 **Module coordinator:**

Prof. Dr. Thomas Zentgraf, Prof. Dr. Christine Silberhorn

13 **Further notes:**

none

Physics and Technology of Nanomaterials

Physik und Technologie von Nanomaterialien

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Experimental Physics	180	6	1st	Winter semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Physics and Technology of Nanomaterials	Lect	30	60	Elective	up to 240
b)	Physics and Technology of Nanomaterials	Exerc	30	60	Elective	up to 30

2 Options within the module:

none

3 Requirements for admission:

none

4 Contents:

- Thermodynamic and crystallographic foundations of nanomaterials
- Preparation of thin films from the liquid phase and vacuum
- Patterning 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 advanced lithography processes
- Preparation, processing and application of one-, two- and three-dimensional nanoobjects (nanowires and nanotubes, graphene and related materials, nanoclusters, core-shell structures)

5 Learning outcomes / Skills:

The students acquire the skills to develop technological concepts for the preparation of nanostructured materials and to evaluate the prospects for their technical realization.

The students

- understand the particular properties that materials acquire by means of nanostructuring,
- know different basic concepts and processes for the preparation of structures with nanoscale size in one, two or three dimensions,
- understand the physical background of these processes at the atomistic or molecular level,
- can employ qualitative and quantitative models that describe such processes,
- are able to transfer the methods to new problems and materials across disciplinary boundaries and to combine them in different ways,
- are capable of autonomously learning about additional technologies by studying technical literature and online sources and to present these in a well-considered manner.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade

	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

The module is also used in the master programs Optoelectronics and Photonics as well as Materials Science.

12 **Module coordinator:**

Prof. Dr. Jörg Lindner, Prof. Dr. Dirk Reuter

13 **Further notes:**

none

Quantum Optics

Quantenoptik

Module group:	**Workload (h):**	**CP:**	**Semester of study:**	**Cycle:**	**Duration (sem.):**
Experimental Physics	180	6	1st	Winter semester	1

1 **Module structure:**

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Quantum Optics	Lect	30	60	Elective	up to 240
b)	Quantum Optics	Exerc	30	60	Elective	up to 30

2 **Options within the module:**

none

3 **Requirements for admission:**

none

4 **Contents:**

In this module, the underlying concepts required to study quantum optics using light are presented. The following topics are discussed in detail:

- Photon statistics and detection of quantum light
- Underlying principles of field quantization
- Coherent states and phase-space representation of light
- Beam splitters and interferometers in quantum optics
- Nonclassical light, squeezed states
- Correlation functions and quantum coherence

5 **Learning outcomes / Skills:**

The students are expected to understand the fundamental concepts of quantum optics, including knowledge of specific phenomena that distinguish quantum-optical observations from their classical counterparts.

The students

- are comfortable with abstract theoretical concepts from quantum optics and can relate these to concrete experimental scenarios,
- are able to use calculation methods from theoretical quantum mechanics in order to solve practical problems in experimental quantum optics,
- can distinguish specific quantum-optical observations from purely classical optical experiments,
- understand the principle of field quantization and the implications for the definition of a photon and the formally correct characterization of wave-particle duality,
- understand the modelling of “classical” laser light and the significance of photon statistics,
- are proficient in calculating quantum interference in a range of setups,
- can judge the applicability of nonclassical states of light in practical scenarios.

6 **Assessment:**

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or	Weights for

		length	module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

The module is also used in the master program Optoelectronics and Photonics.

12 **Module coordinator:**

Prof. Dr. Christine Silberhorn, Jun.-Prof. Dr. Tim Bartley

13 **Further notes:**

none

Laboratory Course

Physikalisches Projektpraktikum

Module group:	**Workload (h):**	**CP:**	**Semester of study:**	**Cycle:**	**Duration (sem.):**
Experimental Physics	180	6	1st–2nd	Every semester	2

1 **Module structure:**

	Course	**Type**	**Contact time (h)**	**Self-study (h)**	**Status (C/E)**	**Group size (students)**
a)	Laboratory Course	Lab	60	120	Elective	4 (two groups supervised in parallel)

2 **Options within the module:**

none

3 **Requirements for admission:**

none

4 **Contents:**

The laboratory course comprises experiments from optoelectronics and photonics as well as materials science. The students choose four experiments from a list announced in the Campus Management System. Experiments on the following topics are available: Ellipsometry and angle-resolved optical analysis, optical waveguide characterization, photon-pair sources based on parametric down-conversion, diode-laser-pumped solid-state laser with second-harmonic generation, optical length measurements, characterization of optoelectronic devices: LED laser, nonlinear optics on a computer, photodetectors, optical communications and high-frequency engineering, simulation of electromagnetic fields, modern lighting devices, correlation microscopy, etc.

5 **Learning outcomes / Skills:**

The students are encouraged to learn independent experimental work by performing small research-related projects with well-defined tasks. In all experiments, a substantial focus is on independently designing proper set-ups and on performing the experimental work and analysis. This laboratory course thus forms a bridge between the advanced physics lab course in the bachelor program, where most of the experiments are carried out under close guidance on completely assembled set-ups, and the scientific work to be done within the modules of the research phase and the master's thesis. The tasks are designed to go significantly beyond standard textbook topics and to include aspects of technical applications that are deemed relevant for future professional work as a physicist in a R&D working environment.

The students

- learn how to perform experimental work on their own by executing small research-related projects with well-defined tasks,
- learn to use modern complex experimental equipment and methods in a real research-near environment within different working groups,
- acquire skills to study scientific literature written in English in preparation of the experiments to be performed and also for the documentation of the obtained results, which should be written in the style of a scientific publication,
- are able to communicate scientific results in the context of current research.

6 **Assessment:**

[] Final module examination [X] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Examination on the four experiments		100%

The examination extends over four experiments. Each experiment comprises the preparation (including literature research), the actual execution (including feedback to comments given by the advisors), the written report (approx. 10 pages plus appendices, with literature review), a short presentation and an oral examination based on the written report (approx. 15 min.). The overall grade is determined from the written reports (including presentations and oral examinations) of the four experiments with equal weights.

7 Certified participation:

To	Form	Duration or length	Certified participation
			none

8 Requirements for participating in examinations:

Attendance during the experiments is a requirement for participating in the examination.

9 Requirements for awarding credit points:

Credit points are awarded if the final module examination has been passed.

10 Weight for overall grade:

The module is weighted according to credit points (factor: 1).

11 Use of the module in other programs:

The module is also used in the master programs Optoelectronics and Photonics as well as Materials Science.

12 Module coordinator:

Prof. Dr. Christine Silberhorn, Prof. Dr. Jörg Lindner

13 Further notes:

None

Quantum Mechanics II

Quantenmechanik II

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
	240	8	1st	Winter semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Quantum Mechanics II	Lect	60	75	Compuls.	up to 240
b)	Quantum Mechanics II	Exerc	30	75	Compuls.	up to 30

2 Options within the module:

none

3 Requirements for admission:

none

4 Contents:

- CGS unit system, axiomatic formulation of quantum mechanics
- Time-independent and time-dependent perturbation theory
- Particles in electromagnetic fields
- Electron spin
- Elements of relativistic quantum mechanics
- Path-integral formulation of quantum mechanics and Green functions
- Many-particle systems

5 Learning outcomes / Skills:

The students are expected to understand the advanced concepts of quantum mechanics, to master the relevant mathematical tools and to recognize the relations to other branches of physics.

The students

- know how to apply time-independent and time-dependent perturbation theory,
- are able to mathematically describe quantum-mechanical particles in electromagnetic fields,
- are able to work with spinors and spin operators,
- are familiar with different quantum-mechanical equations of motions (Schrödinger, Pauli, Klein-Gordon, Dirac), their scopes and limitations,
- understand important relativistic phenomena and effects, such as the Klein paradox, Rashba effect and Zitterbewegung,
- are able to describe quantum-mechanical systems by means of propagators, i.e., Green functions,
- understand the description of quantum-mechanical many-particle systems with the occupation-number formalism and field operators, they can apply these concepts to simple model systems.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination	120–180 min.	100%

	or oral examination	30–45 min.	

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**
none

9 **Requirements for awarding credit points:**
Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**
The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**
none

12 **Module coordinator:**
Prof. Dr. Wolf Gero Schmidt, Prof. Dr. Arno Schindlmayr

13 **Further notes:**
none

Group Theory

Gruppentheorie

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Theoretical Physics	180	6	2nd	Summer semester	1

1 **Module structure:**

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Group Theory	Lect	30	60	Elective	up to 240
b)	Group Theory	Exerc	30	60	Elective	up to 30

2 **Options within the module:**

none

3 **Requirements for admission:**

none

4 **Contents:**

The essential ideas, tools and concepts of group theory of finite discrete symmetry groups are taught in this module. The focus will be on point groups and space groups which are of particular importance for molecular and condensed matter physics. Furthermore, continuous groups and double groups are introduced with their corresponding irreducible representations.

- Symmetry groups, unitary matrices and characters
- Notation systems
- Representation theory
- Point groups in solid-state theory and their irreducible representations
- Irreducible representations of the translation group and the space groups
- Projection operators
- Applications: Vibrational spectra, Stark effect, band structure
- Rotation group
- Determination of eigenfunctions based on their transformation properties
- Double groups, treatment of spins

5 **Learning outcomes / Skills:**

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

The students

- can determine the symmetry in physical problems, for example in the case of molecules or defects in crystals,
- can find representations for the underlying point and space group,
- can establish connections between the purely mathematical concepts of group theory and physical conditions,
- can derive the influence of symmetry on basic physical properties,

- can make qualitative statements concerning the degeneracy of electronic or vibronic levels,
- can deduce qualitative statements concerning possible dipole transitions,
- can estimate the effect of applied electric or magnetic fields,
- can recognize and mathematically describe effects of symmetry reductions,
- can understand and apply the concepts of special groups, rotation and double groups.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 Certified participation:

To	Form	Duration or length	Certified participation
			none

8 Requirements for participating in examinations:

none

9 Requirements for awarding credit points:

Credit points are awarded if the final module examination has been passed.

10 Weight for overall grade:

The module is weighted according to credit points (factor: 1).

11 Use of the module in other programs:

none

12 Module coordinator:

Prof. Dr. Wolf Gero Schmidt

13 Further notes:

none

Optics of Solid-State Systems and Nanostructures

Optik in Festkörpern und Nanostrukturen

Module group:	**Workload (h):**	**CP:**	**Semester of study:**	**Cycle:**	**Duration (sem.):**
Theoretical Physics	180	6	2nd	Summer semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Optics of Solid-State Systems and Nanostructure	Lect	30	60	Elective	up to 240
b)	Optics of Solid-State Systems and Nanostructure	Exerc	30	60	Elective	up to 30

2 Options within the module:

None

3 Requirements for admission:

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 beats
- Theoretical description of pump-probe and four-wave-mixing experiments
- Microscopic many-body theory for optical excitations in semiconductors and nanostructures
- Semiconductor Bloch equations
- Excitons and further many-body effects
- Relaxation and dephasing
- Self-consistent description of light propagation in solid-state systems and nanostructures

5 Learning outcomes / Skills:

The students

- know the derivation and the basic properties of the optical Bloch equations,
- are able to solve the optical Bloch equations using different approximation strategies and to use their results for the description of linear and nonlinear optical properties,
- are familiar with concepts to describe many-body effects in semiconductor optics and can apply these to the derivation of the semiconductor Bloch equations,
- are able to calculate excitonic effects in linear optical spectra within the framework of the semiconductor Bloch equations and to describe nonlinear optical properties within additional approximations,
- know the basic physical processes that lead to dephasing of the optical polarization and to the energy relaxation of optically excited carrier populations,
- know the basic concepts of the self-consistent description of the light propagation in solids and are able to approximately calculate fundamental effects for simple geometries,
- are aware of the capabilities and limitations of the semiclassical description of the light-matter interaction and can use this knowledge to assess results from the literature.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

None

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

The module is also used in the master program Optoelectronics and Photonics.

12 **Module coordinator:**

Prof. Dr. Torsten Meier, Prof. Dr. Stefan Schumacher

13 **Further notes:**

None

Theory of Quantum Information

Quanteninformationstheorie

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Theoretical Physics	180	6	2nd	Summer semester	1

1 **Module structure:**

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Theory of Quantum Information	Lect	30	60	Elective	up to 240
b)	Theory of Quantum Information	Exerc	30	60	Elective	up to 30

2 **Options within the module:**

none

3 **Requirements for admission:**

none

4 **Contents:**

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

5 **Learning outcomes / Skills:**

The students are expected to learn fundamental concepts of the theory of quantum information and to be capable of comprehending current research articles and performing basic calculations on their own.

The students

- know the modern formulation of quantum mechanics,
- are familiar with the concept of separability/nonseparability and can apply this to statistical operators,
- know the ideas and interpretations that underlie the Einstein-Podolsky-Rosen paradox as well as the quantum-mechanical description of entangled states,
- know the fundamental processes that form the basis of quantum cryptography, quantum computing and quantum teleportation, and they can describe these phenomena with the help of model systems.

6 **Assessment:**

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**
none

9 **Requirements for awarding credit points:**
Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**
The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**
The module is also used in the master program Optoelectronics and Photonics.

12 **Module coordinator:**
Prof. Dr. Torsten Meier, Dr. Matthias Reichelt

13 **Further notes:**
none

Relativistic Quantum Field Theory

Relativistische Quantenfeldtheorie

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Theoretical Physics	180	6	2nd	Summer semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Relativistic Quantum Field Theory	Lect	30	60	Elective	up to 240
b)	Relativistic Quantum Field Theory	Exerc	30	60	Elective	up to 30

2 Options within the module:

none

3 Requirements for admission:

none

4 Contents:

- Basic concepts of relativity: The role of the metric
- Poincaré and Lorentz group, relativistic invariance, gauge invariance
- Elements of relativistic quantum mechanics
- Analytical and numerical solution of Dirac’s equation
- Relativistic covariant formulation of quantum mechanics and electrodynamics
- Covariant Hamilton-Lagrange formalism for fields, second 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 / Skills:

The students become familiar with the underlying concepts of relativistic quantum field theory. They will be able to apply the corresponding methods in different areas, from a relativistic description of simple atomic systems up to complex problems in quantum electrodynamics.

The students

- have an overview of quantum-mechanical problems in which relativistic effects play an important role,
- know analytical and numerical methods to solve Dirac’s equation and are able to apply these to simple systems (e.g., isolated atoms),
- have a clear grasp of the wave-particle duality, which is particularly manifest in quantum field theory,
- have mastered the underlying theoretical concepts and methods of relativistic quantum field theory in the covariant formulation and have a deep understanding of the relation between (relativistic) quantum mechanics, electrodynamics and (classical) Hamiltonian mechanics,
- are able to apply the taught concepts to specific problems in quantum electrodynamics.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

none

12 **Module coordinator:**

Dr. Uwe Gerstmann, Prof. Dr. Wolf Gero Schmidt

13 **Further notes:**

none

Theory of Relativity

Relativitätstheorie

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Theoretical Physics	180	6	2nd	Summer semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Theory of Relativity	Lect	30	60	Elective	up to 240
b)	Theory of Relativity	Exerc	30	60	Elective	up to 30

2 Options within the module:

None

3 Requirements for admission:

None

4 Contents:

- Newtonian mechanics (and gravitation)
- Limitations of the classical description, relativistic effects in physics
- Fundamentals of special relativity:
  - 4-vectors and tensor fields, coordinate transformations, Galilei/Lorentz invariance
  - Energy-momentum tensor, length contraction, time dilation
  - Minkowski space, covariant and contravariant derivative
  - Electromagnetic field tensor, covariant formulation of Maxwell's equations
- General relativity:
  - Strong equivalence principle
  - Curvilinear coordinates, differential geometry (connection and Christoffel symbols)
  - Einstein field equations
  - Space-time curvature, Schwarzschild metric, black holes
  - Robertson-Walker metric, Friedmann's equations, cosmology

5 Learning outcomes / Skills:

The students become familiar with the basic concepts of the theory of relativity. They will be able to apply the corresponding advanced methods to selected problems.

The students

- have an overview of problems in physics where relativistic effects play an important role,
- have mastered the theoretical foundations and methods used in the theory of relativity,
- have a thorough understanding of the relativistic covariant formulation of physical problems and can apply this to selected systems,
- have mastered the basics of differential geometry (metric, connection, etc.) and can use this to draw connections to other areas of physics,
- know methods to solve the Einstein field equations, they can apply these to simple examples (e.g., black holes) and can analyze and discuss the results.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

none

12 **Module coordinator:**

Dr. Uwe Gerstmann, Dr. Matthias Reichelt

13 **Further notes:**

none

Theoretical Quantum Optics

Theoretische Quantenoptik

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Theoretical Physics	180	6	2nd	Summer semester	1

1 **Module structure:**

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Theoretical Quantum Optics	Lect	30	60	Elective	up to 240
b)	Theoretical Quantum Optics	Exerc	30	60	Elective	up to 30

2 **Options within the module:**

none

3 **Requirements for admission:**

none

4 **Contents:**

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

5 **Learning outcomes / Skills:**

The students are expected to learn fundamental concepts of theoretical quantum optics and to be capable of comprehending current research articles and performing basic calculations on their own.

The students

- know the concept of photons and how to use photon operators,
- know the theoretical description of light states that can be prepared in modern experiments,
- are familiar with the statistical properties of light and can interpret measurements on this basis,
- know the phase-space functions of common light states,
- know the different behavior of classical and quantized light with respect to the light-matter interaction,
- know the derivation and analysis of the Jaynes-Cummings model and can transfer this to simple extended model systems.

6 **Assessment:**

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

	Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.
7	**Certified participation:** To | Form | Duration or length | Certified participation | | | none
8	**Requirements for participating in examinations:** none
9	**Requirements for awarding credit points:** Credit points are awarded if the final module examination has been passed.
10	**Weight for overall grade:** The module is weighted according to credit points (factor: 1).
11	**Use of the module in other programs:** The module is also used in the master program Optoelectronics and Photonics.
12	**Module coordinator:** **Dr. Matthias Reichelt**, Prof. Dr. Torsten Meier
13	**Further notes:** none

Nested table of row 7:

To	Form	Duration or length	Certified participation
			none

Many-Body Theory of Solids

Vielteilchentheorie der Festkörper

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Theoretical Physics	180	6	2nd	Summer semester	1

1 **Module structure:**

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Many-Body Theory of Solids	Lect	30	60	Elective	up to 240
b)	Many-Body Theory of Solids	Exerc	30	60	Elective	up to 30

2 **Options within the module:**

none

3 **Requirements for admission:**

none

4 **Contents:**

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

5 **Learning outcomes / Skills:**

The students are expected to understand the underlying concepts of quantum-mechanical many-body theory and to be able to effectively apply common approximation schemes for quantitative calculations of electronic excitation spectra.

The students

- know the definition of Green functions and are able to derive formally exact expressions for ground-state expectation values as well as electronic excitation spectra on this basis,
- comprehend different approximation strategies for Green functions of interacting many-particle systems and can relate these to each other,
- are familiar with the concept of quasiparticles and can apply this to the theoretical description and interpretation of photoemission or other spectroscopic processes,
- are able to calculate excitation energies by themselves for semianalytically solvable model systems within the framework of the *GW* approximation for the electronic self-energy,
- can distinguish between different approximation levels for the solution of the Bethe-Salpeter equation and for specific applications can select an appropriate scheme for computing the dielectric function that describes the relevant physical aspects correctly,
- are aware of the capabilities and limitations of many-body theory with respect to quantitative *ab initio* calculations and are able to assess data reported in the scientific literature on this basis.

6 **Assessment:**

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**
none

9 **Requirements for awarding credit points:**
Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**
The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**
none

12 **Module coordinator:**
Prof. Dr. Arno Schindlmayr, Prof. Dr. Wolf Gero Schmidt

13 **Further notes:**
none

Atomistic Materials Modeling

Atomistic Materials Modeling

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Specialization	180	6	1st	Winter semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Atomistic Materials Modeling	Lect	30	60	Elective	up to 240
b)	Atomistic Materials Modeling	Exerc	30	60	Elective	up to 30

2 Options within the module:

none

3 Requirements for admission:

none

4 Contents:

- Empirical potentials and force fields
- Electronic exchange and correlation interaction
- Density-functional theory
- Wavefunction-based methods
- Basis sets and pseudopotentials
- Calculation of structural and vibrational properties as well as thermodynamic quantities

5 Learning outcomes / Skills:

The students are expected to understand the underlying concepts of atomistic materials modeling and to be able to independently perform atomistic simulations using standard methods of theoretical materials physics.

The students

- know the basic atomistic modeling techniques, their application areas and limitations as well as the relevant nomenclature,
- are able to identify suitable methods to explore the structural properties of molecules, solids and nanostructures,
- are familiar with numerical standard packages for simulations, such as Gaussian and Quantum Espresso, including the choice of meaningful numerical parameters and basis sets,
- are able to discuss and assess the calculated quantities in comparison with original literature data.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7	**Certified participation:** <table><tr><th>To</th><th>Form</th><th>Duration or length</th><th>Certified participation</th></tr><tr><td></td><td></td><td></td><td>none</td></tr></table>
8	**Requirements for participating in examinations:** none
9	**Requirements for awarding credit points:** Credit points are awarded if the final module examination has been passed.
10	**Weight for overall grade:** The module is weighted according to credit points (factor: 1).
11	**Use of the module in other programs:** The module is also used in the master program Materials Science.
12	**Module coordinator:** **Prof. Dr. Wolf Gero Schmidt**, Prof. Dr. Arno Schindlmayr
13	**Further notes:** none

Computational Optoelectronics and Photonics I

Computational Optoelectonics and Photonics I

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Specialization	180	6	1st	Winter semester	1

1 **Module structure:**

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Computational Optoelectronics and Photonics I	Lect	30	60	Elective	up to 240
b)	Computational Optoelectronics and Photonics I	Exerc	30	60	Elective	up to 30

2 **Options within the module:**

none

3 **Requirements for admission:**

none

4 **Contents:**

- Application-oriented introduction to the practical numerical implementation of mathematical problems and the visualization of computed data
- Propagation of light in nanostructured solids
- Quantum-mechanical oscillator inside an optical resonator
- Excitons in low-dimensional semiconductor systems coupled to propagating light fields
- Localized electronic states and their properties in nanostructures
- Basic models of quantum optics and quantum information

5 **Learning outcomes / Skills:**

The students

- obtain a basic understanding of nanostructured solids and their applications in photonic structures based on specific examples,
- are able to numerically implement relevant equations used for the mathematical description of physical systems,
- are able, with guidance, to write their own source codes and to use existing program packages in order to numerically analyze the problems formulated in the lecture,
- are able, with guidance, to numerically treat and analyze high-dimensional systems of nonlinear equations of motion,
- can visualize complex physical problems and display the results appropriately.

6 **Assessment:**

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start

	of teaching by the teacher concerned.
7	**Certified participation:**
8	**Requirements for participating in examinations:** none
9	**Requirements for awarding credit points:** Credit points are awarded if the final module examination has been passed.
10	**Weight for overall grade:** The module is weighted according to credit points (factor: 1).
11	**Use of the module in other programs:** The module is also used in the master program Optoelectronics and Photonics.
12	**Module coordinator:** **Prof. Dr. Stefan Schumacher**, Dr. Matthias Reichelt
13	**Further notes:** none

Certified participation (item 7):

To	Form	Duration or length	Certified participation
			none

Computational Optoelectronics and Photonics II

Computational Optoelectonics and Photonics II

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Specialization	180	6	2nd	Summer semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Computational Optoelectronics and Photonics II	Lect	30	60	Elective	up to 240
b)	Computational Optoelectronics and Photonics II	Exerc	30	60	Elective	up to 30

2 Options within the module:

none

3 Requirements for admission:

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
- Propagation of light coupled to the nonlinear optical excitations in a material
- Applications of nonlinear optical propagation effects, such as bistability and solitons

5 Learning outcomes / Skills:

The students

- deepen, building on the module Optoelectronics and Photonics I, their understanding of nanostructured solids and their application in photonic structures, based on specific examples,
- are able to apply methods of many-particle theory to nanostructured solids and to numerically solve the resulting equations,
- are able to compute the nonlinear optical response of nanostructured solids,
- can independently implement mathematical formulations of physical models numerically,
- can independently develop computer codes in order to numerically analyze problems covered in the lectures.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7	**Certified participation:** <table><tr><th>To</th><th>Form</th><th>Duration or length</th><th>Certified participation</th></tr><tr><td></td><td></td><td></td><td>none</td></tr></table>
8	**Requirements for participating in examinations:** none
9	**Requirements for awarding credit points:** Credit points are awarded if the final module examination has been passed.
10	**Weight for overall grade:** The module is weighted according to credit points (factor: 1).
11	**Use of the module in other programs:** The module is also used in the master program Optoelectronics and Photonics.
12	**Module coordinator:** **Prof. Dr. Stefan Schumacher**, Dr. Matthias Reichelt
13	**Further notes:** none

Computational Spectroscopy

Computational Spectroscopy

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Specialization	180	6	2nd	Summer semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Computational Spectroscopy	Lect	30	60	Elective	up to 240
b)	Computational Spectroscopy	Exerc	30	60	Elective	up to 30

2 Options within the module:

none

3 Requirements for admission:

none

4 Contents:

- General foundations: Time-dependent perturbation theory, Fermi’s Golden Rule, linear response, Berry phases, quasiparticle excitations
- Infrared and Raman spectroscopy
- Linear and nonlinear optical spectra
- Core-level spectroscopy: XPS
- X-ray absorption: XAS, XANES, (N)EXAFS
- Circular dichroism (XMCD)
- Magnetic resonance (NMR and EPR)
- Electron transport, photo currents
- Imaging spectroscopy (STM and AFM)

5 Learning outcomes / Skills:

The students become familiar with the basic concepts of computer-assisted calculations (simulations) of spectroscopic material properties. They will be able to apply these concepts for numerical predictions to be compared with experimental data.

The students

- can identify and analyze problems in materials science relating to spectroscopy,
- are aware that modern spectroscopic experiments can often be analyzed to full extent only by comparing to theoretical data,
- know the underlying quantum-mechanical strategies and computational concepts required for atomistic simulations of materials and the prediction of their spectroscopic properties,
- can choose an adequate level of approximation for a given atomic structure (by weighting numerical cost vs. accuracy) and can apply this to selected problems,
- are able to discuss the obtained theoretical results in the context of experimental data and to correlate them with current research problems in materials science.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or	Weights for

		length	**module grade**
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	**Form**	**Duration or length**	**Certified participation**
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

The module is also used in the master program Materials Science.

12 **Module coordinator:**

Dr. Uwe Gerstmann, Prof. Dr. Arno Schindlmayr

13 **Further notes:**

none

Semiconductor Epitaxy

Halbleiterepitaxie

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Specialization	180	6	2nd	Summer semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Semiconductor Epitaxy	Lect	30	60	Elective	up to 240
b)	Semiconductor Epitaxy	Exerc	30	60	Elective	up to 30

2 Options within the module:

none

3 Requirements for admission:

none

4 Contents:

- Fundamentals (fundamentals of crystal structures, elastic properties of heterostructures, dislocations)
- Thermodynamics of layer growth (equilibrium states, crystal growth)
- Atomistic aspects of layer growth (surface structure, kinetic processes during layer growth, self-assembled nanostructures)
- Methods of semiconductor epitaxy (molecular beam epitaxy MBE, metalorganic vapor phase epitaxy MOVPE)
- Characterization methods (in-situ analysis via RHEED, high-resolution X-ray diffraction HRXRD)

5 Learning outcomes / Skills:

The students familiarize themselves with the fundamental concepts of semiconductor epitaxy including fabrication, properties and characterization of semiconductor heterostructures.

The students

- have a comprehensive qualitative understanding of semiconductor epitaxy,
- know the basic principles concerning the quantitative description of the relevant phenomena,
- are able to apply their knowledge to problems in the area of semiconductor epitaxy, to discuss the results and to place them into the context of the field.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7	**Certified participation:** <table><tr><th>To</th><th>Form</th><th>Duration or length</th><th>Certified participation</th></tr><tr><td></td><td></td><td></td><td>none</td></tr></table>
8	**Requirements for participating in examinations:** none
9	**Requirements for awarding credit points:** Credit points are awarded if the final module examination has been passed.
10	**Weight for overall grade:** The module is weighted according to credit points (factor: 1).
11	**Use of the module in other programs:** The module is also used in the master program Materials Science.
12	**Module coordinator:** **Prof. Dr. Dirk Reuter**, Prof. Dr. Donat As
13	**Further notes:** none

Integrated Optics and Photonics

Integrierte Optik und Photonik

Module group:	**Workload (h):**	**CP:**	**Semester of study:**	**Cycle:**	**Duration (sem.):**
Specialization	180	6	1st	Winter semester	1

1 **Module structure:**

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Integrated Optics and Photonics	Lect	30	60	Elective	up to 240
b)	Integrated Optics and Photonics	Exerc	30	60	Elective	up to 30

2 **Options within the module:**

none

3 **Requirements for admission:**

none

4 **Contents:**

- Propagation of electromagnetic waves in optical waveguides (wave equation, boundary conditions and modal dispersion relations of planar waveguides)
- Selected materials and fabrication methods (ion exchange in glasses and crystals, indiffused waveguides in $LiNbO_3$, epitaxially grown waveguides in semiconductor materials)
- Coupled-mode theory (description via eigenmodes of the unperturbed system, description via local normal modes of the actual system)
- Electro-optic devices (electro-optic effect in dielectric crystals, modulators and switches)
- Nonlinear optical devices

5 **Learning outcomes / Skills:**

The students are expected to understand the underlying concepts of integrated optics and photonics as well as their applications.

The students

- have the ability to recognize and analyze questions and problems in integrated optics and to distinguish them from conventional classical optics,
- are able to quantitatively describe wave propagation in guided structures and to apply this (with approximations) to different waveguide geometries on their own,
- are capable of describing the functional principle of integrated optical devices, based on underlying physical principles, and of modelling simple devices on their own either analytically or numerically using the coupled-mode theory,
- are able to autonomously analyze complex integrated optical structures, to identify the different functional components and to describe their roles within the structure,
- can independently study current scientific articles (written in English) on integrated optical devices and photonic structures.

6 **Assessment:**

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade

	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

None

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

The module is also used in the master program Optoelectronics and Photonics.

12 **Module coordinator:**

Prof. Dr. Christine Silberhorn, Dr. Harald Herrmann

13 **Further notes:**

None

Ion Beam Analysis

Ionenstrahlanalyse

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Specialization	180	6	1st	Winter semester	1

1 **Module structure:**

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Ion Beam Analysis	Lect	15	30	Elective	up to 240
b)	Ion Beam Analysis	Lab	30	60	Elective	up to 5
c)	Ion Beam Analysis	Sem	15	30	Elective	up to 30

2 **Options within the module:**

none

3 **Requirements for admission:**

none

4 **Contents:**

This module is offered as a block course in collaboration with the Ruhr-Universität Bochum at the RUBION accelerator laboratory and gives an introduction of nuclear solid-state physics and applications of accelerators.

a) Lecture: Fundamentals of ion-solid interaction and its applications for materials analysis and modification, in particular:

- Ion sources, ion optics, functional principles of accelerators
- Interaction of ionizing radiation with biological organisms, radiation protection
- Thin-film analysis of solids with Rutherford Backscattering Spectroscopy (RBS)
- Trace-element analysis with Nuclear Reaction Analysis (NRA)
- Element detection with particle-induced X-ray emission (PIXE)
- Ion-solid interaction, ion ranges, defect formation
- Doping of semiconductors with ion implantation
- Applications of ion accelerators in astrophysics, geophysics, nuclear physics and medical physics
- Nanopatterning with ion beams

b) Laboratory: Preparation and examination of samples using the accelerators at RUBION as part of projects dealing with topics of the lecture course.

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

5 **Learning outcomes / Skills:**

The students

- understand the technical principles of particle accelerators and the corresponding experiments, the underlying concepts of the ion-solid interaction and their applications for the nuclear analysis of solids and the modification of surfaces with ion beams,
- are familiar with the beam-time operation at a large-scale research facility,
- can design experiments for analyzing solids and modifying surfaces with ion beams on their own, they can carry these out in cooperation with the operators of an accelerator, and they can analyze the results, partly by making use of appropriate software packages,
- are able to transfer the methods to analogous problems and to evaluate and critically assess results reported in the literature based on their experience,

- have experience in web-based cooperation of inter-university teams.

6 **Assessment:**

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
b)	Written report	ca. 30 pages	100%
c)	followed by oral presentation	ca. 30 min.	

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

The module is also used in the master program Materials Science.

12 **Module coordinator:**

Prof. Dr. Jörg Lindner

13 **Further notes:**

none

Microscopy and Spectroscopy with Electrons

Mikroskopie und Spektroskopie mit Elektronen

Module group:	**Workload (h):**	**CP:**	**Semester of study:**	**Cycle:**	**Duration (sem.):**
Specialization	180	6	1st	Winter semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Microscopy and Spectroscopy with Electrons	Lect	30	60	Elective	up to 240
b)	Microscopy and Spectroscopy with Electrons	Exerc	30	60	Elective	up to 30

2 Options within the module:

none

3 Requirements for admission:

none

4 Contents:

Students acquire fundamental knowledge of transmission electron microscopy and its applications to characterize materials on the nanometer and sub-nanometer scale.

- Electron optical components and beam paths in (scanning) transmission electron microscopes (S)TEM
- TEM sample preparation
- Imaging techniques and types of contrasts
- Electron diffraction
- 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 as well as plasmons
- Energy-filtered transmission electron microscopy EFTEM
- In-situ and cryo methods

5 Learning outcomes / Skills:

Students are acquainted with the technical capabilities of modern transmission electron microscopy to gain insight into the structural properties of materials, based on a quantum-mechanical treatment of the interaction of electron waves with condensed matter.

The students

- understand the propagation of electron waves in crystalline materials with and without lattice defects as well as the transport of electron beams through the microscope from the source to the detector,
- are able to select suitable TEM modes for a variety of problems and to interpret the generated contrasts,
- are able to analyze simple electron-diffraction patterns,
- are capable of interpreting TEM images documented in the literature in terms of the real structure of matter,
- can extract information concerning the atomic composition and electronic structure of solids from EELS and EDS spectra,

- know how to use standard software packages of electron microscopy.

6 **Assessment:**

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

The module is also used in the master program Materials Science.

12 **Module coordinator:**

Prof. Dr. Jörg Lindner

13 **Further notes:**

none

Low-Dimensional Semiconductor Systems: Electrical Properties

Niedrigdimensionale Halbleitersysteme: Elektrische Eigenschaften

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Specialization	180	6	2nd	Summer semester	1

1 **Module structure:**

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Low-dimensional Semiconductor Systems: Electrical Properties	Lect	30	60	Elective	up to 240
b)	Low-dimensional Semiconductor Systems: Electrical Properties	Exerc	30	60	Elective	up to 30

2 **Options within the module:**

none

3 **Requirements for admission:**

none

4 **Contents:**

- Heterostructures (repetition)
- Electrical and transport properties
- Shubnikov-de Haas effect and magnetic fields
- Integer and fractional quantum Hall effect
- Carrier transport and scattering mechanisms
- Coherent and mesoscopic systems
- Heterojunction FET, HEMT
- HBT, THET and RTD
- Coulomb blockade and SET
- Aharonov-Bohm effect
- CV spectroscopy on quantum dots

5 **Learning outcomes / Skills:**

The students are expected to understand the underlying concepts of low-dimensional semiconductor systems and to be able to apply them autonomously to problems from the field.

The students

- have a basic knowledge of the electrical properties of semiconductor heterostructures, quantum wells, quantum wires and quantum dots,
- have knowledge of the transport properties and the different scattering mechanisms that are effective in low-dimensional structures,
- understand the integer and fractional quantum Hall effect,
- have knowledge of various semiconductor devices that exploit low-dimensional properties to enhance the device performances (e.g., HEMT, HBT and RTD) and have an idea of the functional principle of single-electron transistors,
- are able to apply their knowledge to the design and operation of modern low-dimensional semiconductor devices.

6 **Assessment:**

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

none

12 **Module coordinator:**

Prof. Dr. Donat As, Prof. Dr. Artur Zrenner

13 **Further notes:**

none

Low-Dimensional Semiconductor Systems: Optical Properties

Niedrigdimensionale Halbleitersysteme: Optische Eigenschaften

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Specialization	180	6	2nd	Winter semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Low-dimensional Semiconductor Systems: Optical Properties	Lect	30	60	Elective	up to 240
b)	Low-dimensional Semiconductor Systems: Optical Properties	Exerc	30	60	Elective	up to 30

2 Options within the module:

none

3 Requirements for admission:

none

4 Contents:

- Fabrication of nanostructures
- Heterostructures, quantum wells
- Optical processes in quantum wells, inter- and intra-band transitions
- Coupled quantum wells, superlattices and excitons
- Quantum wires and quantum dots
- Modulation doping
- Influence of electric fields (Stark effect)
- Single-photon emitters
- Quantum cascade effect

5 Learning outcomes / Skills:

The students are expected to understand the underlying concepts of low-dimensional semiconductor systems and to be able to apply them autonomously to problems from the field.

The students

- have a basic knowledge of the optical properties of semiconductor heterostructures, quantum wells, quantum wires and quantum dots,
- have a basic knowledge of the growth and fabrication of nanostructures,
- have a knowledge of the excitonic properties of low-dimensional semiconductor structures and of the influence of electrical fields on the optical properties of modern optoelectronic semiconductor devices,
- are able to apply their knowledge to the design and operation of low-dimensional semiconductor devices,
- have a knowledge of the functional principles and applicability of advanced light emitters, such as single-photon emitters and quantum cascade lasers.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination	120–180 min.	100%

	or oral examination	30–45 min.	

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

none

12 **Module coordinator:**

Prof. Dr. Donat As, Prof. Dr. Artur Zrenner

13 **Further notes:**

none

Optoelectronic Semiconductor Devices

Optoelektronische Halbleiterbauelemente

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Specialization	180	6	1st	Winter semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Optoelectronic Semiconductor Devices	Lect	30	60	Elective	up to 240
b)	Optoelectronic Semiconductor Devices	Exerc	30	60	Elective	up to 30

2 Options within the module:

none

3 Requirements for admission:

none

4 Contents:

The first part of the lecture gives an overview of the physics of light-emitting diodes and the static properties of semiconductor lasers starting from basic solid-state physics up to 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 principles of various semiconductor photodetectors.

- Relevance of optoelectronic semiconductor devices
- Light-emitting diodes – LED
- Laser diodes – static properties
- Laser diodes – dynamic properties
- Optoelectronic detectors

5 Learning outcomes / Skills:

The students are expected to understand the fundamental concepts of optoelectronic semiconductor devices and to be able to apply these to relevant problems on their own.

The students

- know the fundamental principles of light-emitting semiconductor devices, such as LEDs or laser diodes,
- have a physical understanding of the static, dynamic and spectral properties of LEDs and semiconductor lasers,
- can apply their fundamental knowledge of the influence of quantum structures on the properties of modern semiconductor devices,
- are able to apply their knowledge to the design and operation of optoelectronic semiconductor devices,
- have a basic knowledge of the functional principles and the areas of application of various semiconductor photodetectors.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination	120–180 min.	100%

	or oral examination	30–45 min.	

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

The module is also used in the master program Optoelectronics and Photonics.

12 **Module coordinator:**

Prof. Dr. Dirk Reuter, Prof. Dr. Donat As

13 **Further notes:**

none

Photonic Nanostructures

Photonische Nanostrukturen

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Specialization	180	6	1st	Winter semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Photonic Nanostructures	Lect	30	60	Elective	up to 240
b)	Photonic Nanostructures	Exerc	30	60	Elective	up to 30

2 Options within the module:

none

3 Requirements for admission:

none

4 Contents:

- Light-matter interaction (Maxwell’s equations in matter, wave equation and Helmholtz equation, optical response of matter, 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: microdisk and ring resonators, electromagnetic fields in periodic media, symmetries and photonics, photonic crystal membranes; optical resonators III: defects in photonic crystals)
- Plasmonic nanostructures (surface and interface plasmon-polaritons, metallic nanoparticles, optical metamaterials)

5 Learning outcomes / Skills:

The students are expected to be able to apply fundamental concepts of the interaction of light with nanostructures correctly to current problems of modern physics and to work out solutions for typical problems by themselves.

The students

- can recognize problems in the field of nanooptics by themselves and distinguish them from the optics of macroscopic objects,
- have the ability to describe and assess effects resulting from the interaction of light with dielectric and metallic nanostructures,
- can develop solutions to complex problems associated with optical nanostructures by themselves and argue their applicability based on the acquired knowledge,
- can, under guidance, develop and apply reasonable analytic and numerical approximation schemes for problems in nanophotonics,
- are able to deal with recent technical literature in English language on topics in nanooptics.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination	120–180 min.	100%

	or oral examination	30–45 min.	

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

This module is also used in the master programs Optoelectronics and Photonics as well as Chemistry.

12 **Module coordinator:**

Prof. Dr. Cedrik Meier, Prof. Dr. Thomas Zentgraf

13 **Further notes:**

none

Quantum Electronics

Quantenelektronik

Module group:	**Workload (h):**	**CP:**	**Semester of study:**	**Cycle:**	**Duration (sem.):**
Specialization	180	6	2nd	Summer semester	1

1 **Module structure:**

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Quantum Electronics	Lect	30	60	Elective	up to 240
b)	Quantum Electronics	Exerc	30	60	Elective	up to 30

2 **Options within the module:**

none

3 **Requirements for admission:**

none

4 **Contents:**

Basic concepts of quanum electronics, their optical, electrical and optoelectronic foundations as well as their practical applications. Understanding and mathematical formulation of the physical issues and models.

- Experimental characterization of quantum systems
- Atoms and quantum structures as two-level systems
- Coherent light-matter interaction
- Quantum amplifiers
- Solid-state quantum bits
- Quantum bits in strong optical fields and resonators
- Functional structures and practical applications

5 **Learning outcomes / Skills:**

The students

- possess a profound technical knowledge in the area of quantum electronics,
- possess a profound knowledge about two-level systems,
- possess a profound knowledge about the light-matter interaction in strong fields,
- are able to mathematically describe the physical principles of quantum electronics,
- are able to derive fundamental physical principles of quantum electronics,
- can clearly communicate the physical and technical foundations as well as practical applications of quantum electronics.

6 **Assessment:**

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

This module is also used in the master programs Optoelectronics and Photonics.

12 **Module coordinator:**

Prof. Dr. Artur Zrenner, Prof. Dr. Christine Silberhorn

13 **Further notes:**

none

Quantum Communication and Information

Quantenkommunikation und Quanteninformationsverarbeitung

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Specialization	180	6	2nd	Summer semester	1

1 **Module structure:**

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Quantum Communication and Information	Lect	30	60	Elective	up to 240
b)	Quantum Communication and Information	Exer	30	60	Elective	up to 30

2 **Options within the module:**

none

3 **Requirements for admission:**

none

4 **Contents:**

The module aims to impart the basic concepts and protocols of quantum communication and quantum information processing.

- Introduction to the underlying principles of quantum information (mathematical formulation of the concept of information, qubits and quantum gates)
- Quantum measurements
- Entangled states
- Quantum teleportation and quantum dense coding
- Quantum cryptography (protocols, experimental implementations, security proofs and eavesdropper attacks)
- Entanglement distillation and quantum repeaters

5 **Learning outcomes / Skills:**

The students are expected to understand the underlying concepts of quantum communication and to know the main protocols and their practical implementations.

The students

- are able to work on interdisciplinary topics and, in particular, to acquire the basics of different disciplines,
- are familiar with the abstract concepts of information theory and quantum physics, and they can relate these with relevant experiments from physics,
- understand the fundamental idea of novel quantum technologies, the exploitation of genuine quantum-physical characteristics for practical applications,
- understand the notion of entangled states and its relevance for the modern interpretation of quantum physics,
- know the basic protocols of quantum communication and quantum information processing,
- are able to familiarize themselves with contemporary research topics, which may not yet be presented in textbooks, and thus they get prepared for future independent research work,
- can realistically evaluate the prospects and limitations of future technologies.

6 **Assessment:**

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 Certified participation:

To	Form	Duration or length	Certified participation
			none

8 Requirements for participating in examinations:

none

9 Requirements for awarding credit points:

Credit points are awarded if the final module examination has been passed.

10 Weight for overall grade:

The module is weighted according to credit points (factor: 1).

11 Use of the module in other programs:

The module is also used in the master program Optoelectronics and Photonics.

12 Module coordinator:

Prof. Dr. Christine Silberhorn

13 Further notes:

none

Spintronics

Spintronik

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
Specialization	180	6	2nd	Summer semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Spintronics	Lect	30	60	Elective	up to 240
b)	Spintronics	Exerc	30	60	Elective	up to 30

2 Options within the module:

none

3 Requirements for admission:

none

4 Contents:

- Quantum-mechanical description of the 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 read-out of qubits (spin injection and spectroscopy)
- Passive devices in magneto-electronics: GMR, TMR, MRAM
- Active devices: spin-field-effect transistor
- Basics of spin-based quantum information

5 Learning outcomes / Skills:

The students become familiar with the underlying concepts of spin physics, especially spin dynamics. Being aware of the close interaction between experiment and theory, they are able to apply these for the description of spin-based devices.

The students

- have mastered the basic quantum-mechanical concepts of spin physics, especially spin dynamics,
- are aware of the conceptional differences between the description of quantum-mechanical ensembles and single spins,
- have detailed knowledge of measuring techniques based on spin interactions and of their multi-disciplinary application in biology, chemistry, physics and medicine as well as their usage for the read-out of spin-based quantum bits (“qubits”),
- are able to analyze problems in the general area of spin-based electronics and to apply the developed mathematical models to specific devices,
- know the physical properties and special features of spin-based qubits and can place these in a larger context (electronics, informatics, quantum information).

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade

	Written examination or oral examination	120–180 min. 30–45 min.	100%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

none

9 **Requirements for awarding credit points:**

Credit points are awarded if the final module examination has been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

none

12 **Module coordinator:**

Dr. Uwe Gerstmann

13 **Further notes:**

none

English for Technical Purposes II

Technisches Englisch II

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
	180	6	1st–2nd	Every semester	2

1 **Module structure:**

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	English Oral Skills for Students of Natural Sciences	Exerc	30	60	Compuls.	up to 20
b)	Introduction to Academic Writing for MINT Students *oder* English for Profession and Study Abroad	Exerc	30	60	Elective	up to 20

2 **Options within the module:**

Choice between the courses “Introduction to Academic Writing for MINT Students” and “English for Profession and Study Abroad”.

3 **Requirements for admission:**

Proof of proficiency in English equivalent to the level B2.1 during the placement test of the Center for Language Studies is required for admission.

4 **Contents:**

English Oral Skills for Students of Natural Sciences:

This course is designed for students of Natural Sciences who would like to broaden their existing knowledge about presentation strategies and to polish their communicative skills for both their studies and future lives as professionals. Practical examples will help students deepen and apply the theoretical background learned in class.

Introduction to Academic Writing for MINT Students:

This course aims at preparing students to write their papers or theses in English. Together, we will explore common features of writing English research papers, which will include, for example, the following topics:

- Paragraphing your paper
- Putting forth hypotheses
- Improving punctuation
- Writing abstracts, analyses and essays

Grammatical accuracy as well as vocabulary expansion will also be addressed.

English for Profession and Study Abroad:

This course is especially designed for students who would like to train both their English writing and oral skills for their future professional life or for a term abroad. Together, we will explore the following topics:

- Making telephone calls and writing e-mails in English language
- Writing CVs and applications, including letters of motivation
- Presentation strategies for selling yourself well
- Studying and living abroad

Grammatical accuracy as well as vocabulary expansion will also be addressed.

5 **Learning outcomes / Skills:**

The students expand their general as well as science-related vocabulary. They are able to participate in scientific discussions, to present research topics orally and in writing using correct English, to produce extended structured reports such as theses or scientific papers, and to communicate orally and in writing in a professional environment in an appropriate way. The course corresponds to the level B2 of the Common European Framework of Reference for Languages.

The students

- are able to write scientific papers for an English-language readership using appropriate vocabulary and correct grammar,
- can create presentations in English language on their own and can communicate research results in scientific talks,
- are able to explain technical issues and argue their own point of view in a clear and sophisticated way in English language.

6 **Assessment:**

[] Final module examination [] Module examination [X] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
a)	Oral presentation or oral examination	ca. 15 min.	50%
b)	Five written reports followed by oral presentation	500 words each ca. 10 min.	50%

Confirmation of how the assessment is to be performed shall be given at the latest in the third week from the start of teaching by the teacher concerned.

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

Regular attendance (no more than three times absent) in the two language courses is required.

9 **Requirements for awarding credit points:**

Credit points are awarded if all partial module examinations have been passed.

10 **Weight for overall grade:**

The module is weighted according to credit points (factor: 1).

11 **Use of the module in other programs:**

none

12 **Module coordinator:**

Dr. Sigrid Behrent

13 **Further notes:**

none

Advanced Seminar

Hauptseminar

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
	120	4	1st–2nd	Every semester	2

1 **Module structure:**

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Advanced Seminar	Sem	30	30	Compuls.	up to 20
b)	Advanced Seminar	Sem	30	30	Compuls.	up to 20

2 **Options within the module:**

none

3 **Requirements for admission:**

none

4 **Contents:**

Within the Advanced Seminar, the students are taught to familiarize themselves with current topics of modern physics, to accumulate relevant information and finally to present their knowledge to the other students in the framework of the seminar. This opportunity to deliver their own presentations is intended to enhance the students' expertise with respect to current research topics as well their personal presentation skills.

5 **Learning outcomes / Skills:**

The students

- can familiarize themselves with a given topic of modern physics on their own and accumulate relevant information by means of individual study and literature research,
- are able to recognize and explain relations between the topic and neighboring fields,
- can design their presentation under pedagogical and disciplinary aspects,
- make use of the acquired experience in order to enhance their personal presentation skills as well as their communication skills when answering scientific questions.

6 **Assessment:**

[] Final module examination [] Module examination [X] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
a)	Oral presentation	ca. 30 min.	50%
b)	Oral presentation	ca. 30 min.	50%

7 **Certified participation:**

To	Form	Duration or length	Certified participation
			none

8 **Requirements for participating in examinations:**

	none
9	**Requirements for awarding credit points:** Credit points are awarded if all partial module examinations have been passed.
10	**Weight for overall grade:** The module is weighted according to credit points (factor: 1).
11	**Use of the module in other programs:** none
12	**Module coordinator:** **Prof. Dr. Cedrik Meier**, Prof. Dr. Torsten Meier
13	**Further notes:** none

Preparation for the Master's Thesis: Theory

Vorbereitung der Masterarbeit: Theorie

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
	450	15	3rd	Every semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Preparation for the Master's Thesis: Theory				Compuls.	1

2 Options within the module:

none

3 Requirements for admission:

Successful completion of the module "Quantum Mechanics II" and at least 48 CP. Additionally, in the case of conditional enrollment, proof that the relevant examinations have been passed.

4 Contents:

The goal of this module is to become familiar with the research field pertaining to the master's thesis by acquiring specific factual expertise of physics and knowledge of the theoretical foundations under individual guidance. In particular, this includes a literature search of recent scientific articles as well as communication with members of the research group in which the master's thesis will be conducted. Depending on the chosen topic and in accord with the advisor, the preparation may also involve attendance of special courses, external training or stays in cooperating external research groups.

5 Learning outcomes / Skills:

The students

- can familiarize themselves with a new research field on their own and get an overview of the current state of research,
- are able to equip themselves with new theoretical concepts and relevant factual physical knowledge and to connect these with existing know-how,
- can structure the know-how acquired from different sources in a systematic way and summarize it in writing using a consistent notation and technical terminology,
- can work together in a research team,
- are able to discuss scientific topics in German and/or English language,
- can prepare a scientific presentation and convey their findings in the context of current research,
- have learned to also handle critical questions in a scientific discussion.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written report followed by oral presentation	ca. 10 pages ca. 25 min.	100%

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<tr><td>7</td><td>Certified participation:
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<tr><td></td><td></td><td></td><td>none</td></tr>
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<tr><td>8</td><td>Requirements for participating in examinations:
none</td></tr>
<tr><td>9</td><td>Requirements for awarding credit points:
Credit points are awarded if the final module examination has been passed.</td></tr>
<tr><td>10</td><td>Weight for overall grade:
The module is weighted according to credit points (factor: 1).</td></tr>
<tr><td>11</td><td>Use of the module in other programs:
none</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr. Cedrik Meier, Prof. Dr. Arno Schindlmayr</td></tr>
<tr><td>13</td><td>Further notes:
none</td></tr>
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Preparation for the Master's Thesis: Methods

Vorbereitung der Masterarbeit: Methodik

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
	450	15	3rd	Every semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Preparation for the Master's Thesis: Methods				Compuls.	1

2 Options within the module:

none

3 Requirements for admission:

Successful completion of the module "Quantum Mechanics II" and at least 48 CP. Additionally, in the case of conditional enrollment, proof that the relevant examinations have been passed.

4 Contents:

The goal of this module is to acquire, under individual guidance, the technical knowledge and abilities that are required for the master's thesis. In the case of a topic from experimental physics, this typically involves instructions about the safe handling of measuring devices and the optimization of the experimental setup; in the case of a topic from theoretical physics, it typically involves instructions about the usage of existing computer programs and their enhancement for numerical simulations. Depending on the chosen topic and in accord with the advisor, besides instructions by members of the research group in which the master's thesis will be conducted, the preparation may also involve attendance of special courses, external training or stays in cooperating external research groups.

5 Learning outcomes / Skills:

The students

- can familiarize themselves, under guidance, with the safe handling of complex measurement devices or scientific computer programs for research purposes,
- are able to use complex experimental devices or computer codes efficiently for research purposes, to adjust and optimize them and to enhance individual components as needed,
- know strategies to identify and eliminate errors or disturbances in complex measurements or numerical simulations,
- can work together in a research team,
- are able to discuss scientific topics in German and/or English language,
- can prepare a scientific presentation and convey their findings in the context of current research,
- have learned to also handle critical questions in a scientific discussion.

6 Assessment:

[X] Final module examination [] Module examination [] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
	Written report followed by oral presentation	ca. 10 pages ca. 25 min.	100%

7 Certified participation:

To	Form	Duration or length	Certified participation
			none

8 Requirements for participating in examinations:

none

9 Requirements for awarding credit points:

Credit points are awarded if the final module examination has been passed.

10 Weight for overall grade:

The module is weighted according to credit points (factor: 1).

11 Use of the module in other programs:

none

12 Module coordinator:

Prof. Dr. Cedrik Meier, Prof. Dr. Arno Schindlmayr

13 Further notes:

none

Master’s Thesis

Masterarbeit

Module group:	Workload (h):	CP:	Semester of study:	Cycle:	Duration (sem.):
	900	30	4th	Every semester	1

1 Module structure:

	Course	Type	Contact time (h)	Self-study (h)	Status (C/E)	Group size (students)
a)	Written master’s thesis				Compuls.	1
b)	Oral defense				Compuls	1

2 Options within the module:

none

3 Requirements for admission:

Successful completion of the modules “Preparation for the Master’s Thesis: Theory” and “Preparation for the Master’s Thesis: Methods”.

4 Contents:

Independent work on a research project under individual guidance, detailed presentation of the problem and the obtained results and discussion of their relevance in the context of current research in the master’s thesis, oral presentation and defense.

5 Learning outcomes / Skills:

The students

- can familiarize themselves independently with a research topic,
- are able to research the international scientific literature with regard to the given topic and get an overview on the current state of research,
- have the ability to familiarize themselves with a complex measurement technique or a complex theoretical concept and can pursue their own research project adhering to scientific methods and standards,
- can work together in a research team,
- can write a scientific thesis independently,
- can structure a scientific presentation about their own results appropriately and present it to an audience with contextual information about the current state of research,
- have learned to also handle critical questions in a scientific discussion and to argue their own point of view,
- know the rules of good scientific practice and adhere to these,
- are able to develop a realistic timetable for their own complex project,
- possess qualifications like self-dependence and the ability to work in a team,
- are proficient in oral German or English for technical purposes.

6 Assessment:

[] Final module examination [] Module examination [X] Partial module examinations

To	Form of assessment	Duration or length	Weights for module grade
a)	Written master’s thesis	40–80 pages	5/6
b)	Oral defense including assessed discussion	45–60 min.	1/6

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<tr><td>8</td><td>Requirements for participating in examinations:
Passing the written master’s thesis is a requirement for participating in the oral defense.</td></tr>
<tr><td>9</td><td>Requirements for awarding credit points:
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<tr><td>12</td><td>Module coordinator:
Prof. Dr. Cedrik Meier, Prof. Dr. Arno Schindlmayr</td></tr>
<tr><td>13</td><td>Further notes:
none</td></tr>
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